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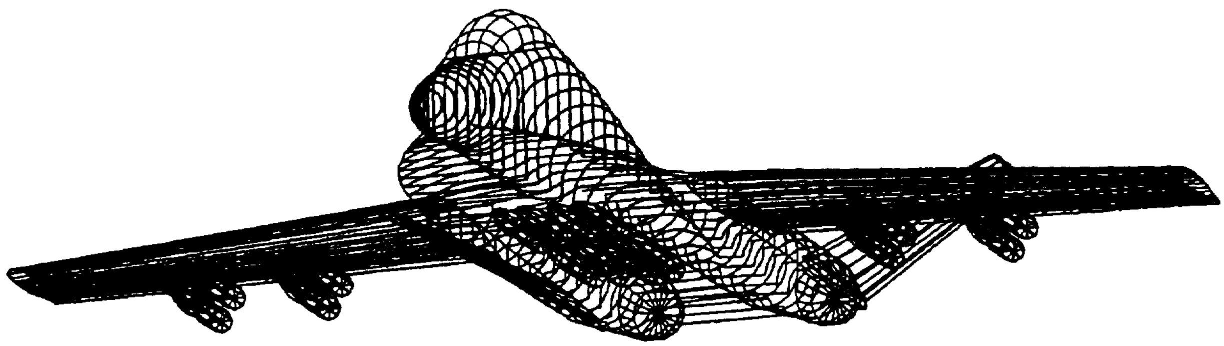
A-2000

Close Air Support Aircraft Design Team



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ABSTRACT

The United States Air Force is currently faced with the problem of providing adequate close air support for ground forces. Air response to troops engaged in combat must be rapid and devastating due to the highly fluid battle lines of the future. The A-2000 is the result of a year long study designed to deliver massive firepower accurately. The low cost A-2000 incorporates:

- Large weapons payload: 13,000 lbs
- Excellent maneuverability: Exceeds re-attack time by 2 seconds. 6.0 g's sustained load factor
- All-weather and terrain following capacity: Integration of LANTIRN Navigation and Targeting System
- Redundant systems: Dual hydraulic and flight control systems
- High survivability: Achieved through carefully placed armor and redundant systems

The A-2000 will use these advantages to fulfill close air support needs of the future.

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Nomenclature

Symbol	Definition	Dimensions
a.c.	aerodynamic center	-
AR	wing aspect ratio	-
b	wing span	ft
c	chord	ft
c	mean geometric chord	ft
c_l	airfoil lift coefficient	-
c_m	airfoil pitching moment	-
c_t	tip chord	ft
C_D	airplane drag coefficient	-
C_L	airplane lift coefficient	-
e	span efficiency factor	-
f	equivalent parasite area	-
I	mass moment of inertia	slug-ft^2
L	lift	lbs
L/D	lift to drag ratio	-
M	free stream Mach number	-
mac	mean aerodynamic chord	ft
n	airplane load factor	-
nmi	nautical miles	nmi
p	perturbed roll rate	rad/sec
Ps	specific excess energy	ft/sec
q	perturbed pitch rate	rad/sec
q_∞	free stream dynamic press.	lbs/ft^2
r	perturbed yaw rate	rad/sec
S	wing planform area	ft^2
S_h	projected horizontal tail area	ft^2
S_v	projected vertical tail area	ft^2
t/c	thickness ratio	-
Tav	thrust available	lbs
u	longitudinal velocity	-
v	velocity	ft/sec
w	airplane weight	lbs
Greek symbols		-
α	angle of attack	deg, rad
θ	pitch attitude	deg, rad
ϕ	roll attitude	deg, rad
β	sideslip	deg, rad
Λ	sweep angle	deg, rad

Subscripts	Definition
c/4	quarter chord
cr	critical
dd	drag divergence

inst	installed
S.L.	sea level
TO	take-off
unist	uninstalled
xx	about body x-axis
wet	wetted
yy	about body y-axis
zz	about body z-axis
Acronyms	
AIAA	American Institute of Aeronautics and Astronautics
AIM	Air Intercept Missile
APU	Auxiliary Power Unit
CRT	Cathode Ray Tube
DATCOM	Data Compendium
ECM	Electronic Counter Measures
FEBA	Forward Edge of Battle Area
FLIR	Forward Looking InfraRed
FOD	Foreign Object Damage
HOTAS	Hands On Throttle and Stick
HDD	Heads Down Display
HUD	Heads Up Display
IFF	Identify Friend or Foe
LANTIRN	Low Altitude Navigation and Targeting by InfraRed at Night
LE	leading edge
LEX	leading edge extension
OBOGS	On-Board Oxygen Generating System
RDTE	Research, Development, Testing and Evaluation
RFP	Request For Proposal
RWR	Radar Warning Receiver
TACAN	Tactical Air Navigation
VHF	Very High Frequency
UHF	Ultra High Frequency
USRA	University Space Research Association

1.0 Introduction

Over the past few decades, the role of Close Air Support (CAS) has changed dramatically. Today and in the future, direct interdiction of attacking ground forces is complicated by advanced anti-aircraft weapons and increasingly fluid battlelines. The design objectives of the 1990/1991 AIAA/General Dynamics Corporation Team Aircraft Design Competition require a CAS aircraft capable of meeting projected battlefield requirements.

1.1 What is CAS?

The basic definition of close air support is the use of air power to interdict battlefield forces in order to slow or halt enemy advancement as well as to provide concentrated firepower for purposes of friendly advancement[1]. The definition, however, leaves open the possibility for many interpretations of how this is best achieved.

In the past, CAS has been a very direct symbiotic effort. Loitering aircraft were directed by ground commanders to positions where firepower was needed. The aircraft often provided direct assistance in close proximity of friendly troops.

Future conflicts will present several new problems to the CAS task. Foremost of these is the fact that highly mobile and maneuverable firepower will make battlefield lines extremely fluid and hard to define[1]. This will have a significant technical impact on the type of aircraft used to fulfill the role. Reduced command and control for such battle conditions place effective response time at a premium[1]. Another CAS problem is the enemy acquisition of small, often shoulder-launched, anti-aircraft weapons. These combined with mobile anti-aircraft guns result in an enemy defense which is several times more deadly than in the past.

With these points in mind, it is feasible that CAS aircraft of the future may focus more on second line battlefield interdiction[1]. In this role, aircraft must penetrate past battle lines to attack advancing second echelon forces and supply units. This tends to incapacitate opponents to an extent that might decisively affect his willingness or ability to continue fighting. The aforementioned points offer some insight into the direction CAS may take. It must be remembered, however, that these are predictions of what might be and do not necessarily reflect what exists at present. With all these points in mind let us examine the current method and the type of aircraft used to perform the CAS mission today.

1.2 CAS Today

One of the most celebrated CAS aircraft of today is the Fairchild Republic A-10. The A-10's performance combines low speed maneuverability with terrain masking techniques. These tactics were not the basis for the initial aircraft design. They arose out of the constantly changing nature of the CAS role. New Soviet anti-aircraft weapons and long range interceptors forced this tactical change. It was fortunate that the A-10's low speed flight and high maneuverability rendered the aircraft readily adaptable to this new set of tactics. An important lesson seen here is that CAS aircraft must be versatile and designed with the future in mind.

1.3 Design Requirements

In view of all that has been previously mentioned, we may now examine the basic battlefield requirements as outlined by the Request For Proposal (Appendix A1).

> "The U.S. Military services are currently struggling with the challenge of providing close air support for ground troops on the battlefield of the future. Mid to high-intensity conflict will be chaotic, intense, highly lethal, and widespread, with operations conducted around the clock. The CAS aircraft must be capable of responsive delivery of effective ordnance in close proximity to friendly ground forces during the day, night, and under-the-weather conditions, and must be capable of surviving in a very high threat environment during mission execution. Near-continuous ground operations correspondingly require high sortie rates and rugged, reliable aircraft capable of operating with little or no maintenance for long periods of time. The low intensity conflict includes terrorist counteraction, foreign internal defense, peacekeeping operations, and peacetime contingency operations. The application of military power often requires precision attack on targets to minimize collateral damage. Also third world, dispersed, or other austere operating sites may require maintenance with little or no support or electrical power."

2.0 Mission Description

The A-2000 must specifically fulfill the following three missions:

1) Design Mission: A sea level mission with full ordnance and attack radius of 250 nmi.
2) Hi-Lo Mission: A mission combining both high level cruise and low level dash to an attack radius of 250 nmi. Full ordnance is carried and a loiter segment included whose length depends on fuel available.
3) Ferry Mission: A high level mission to a range of 1500 nmi.

Figure 2.1.1 shows the three design missions graphically.

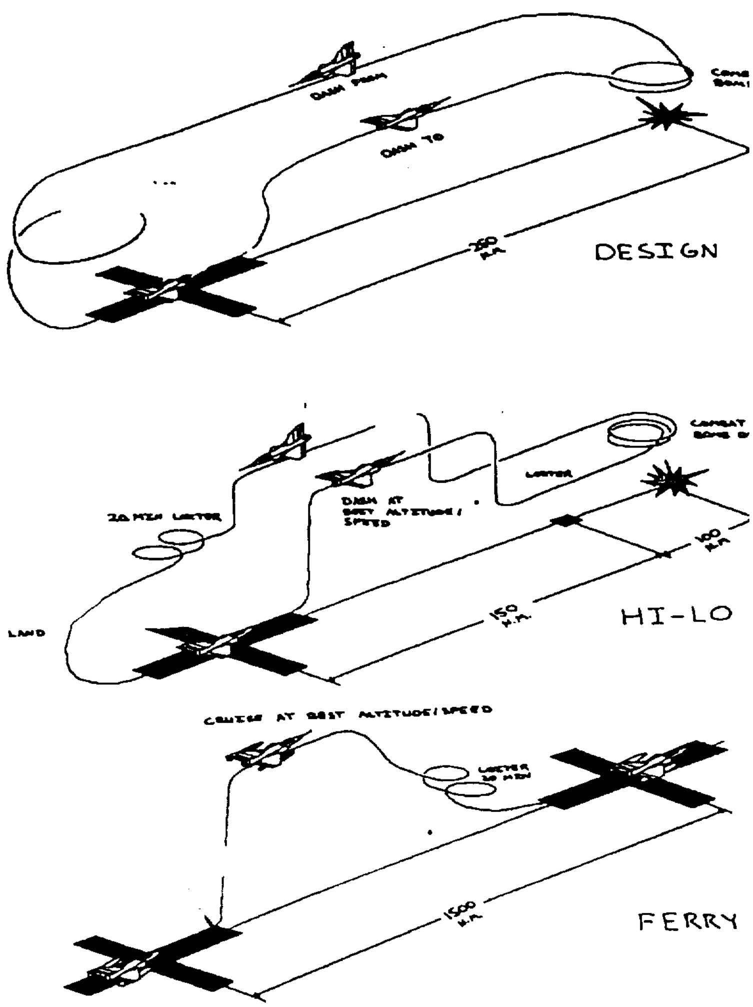


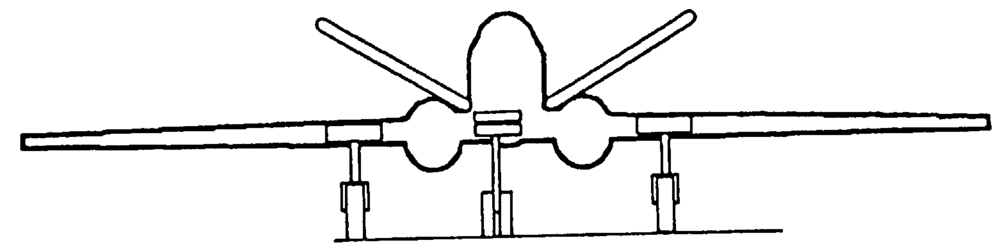
Figure 2.1.1 - A-2000 Mission Profiles

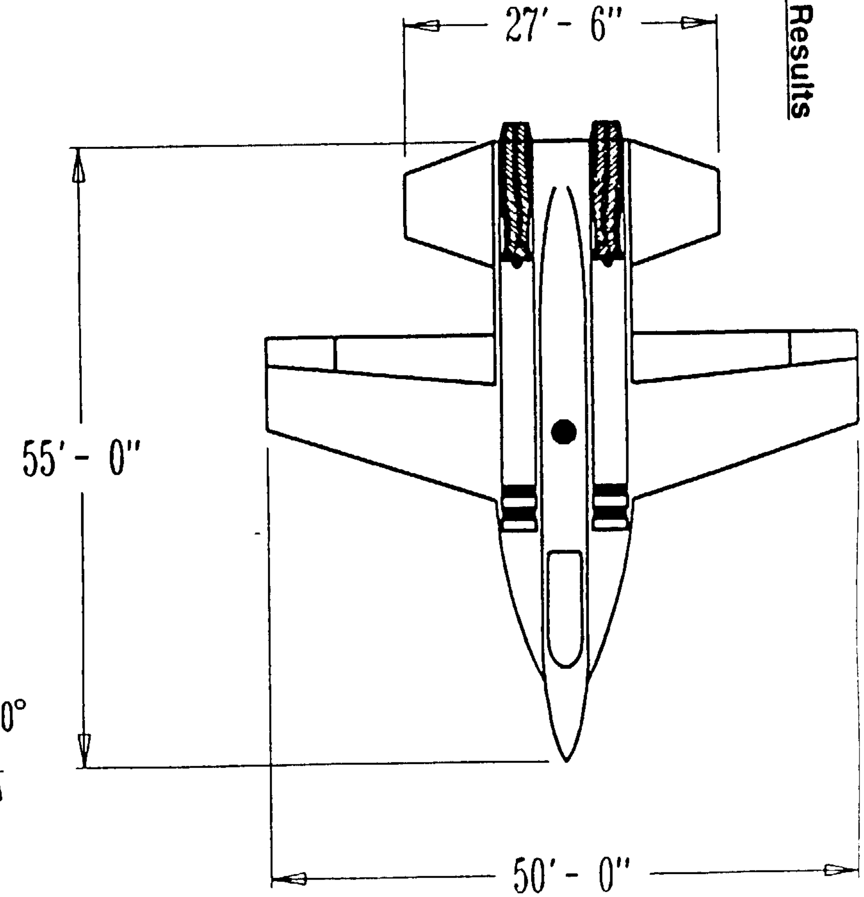
3.0 Design Results

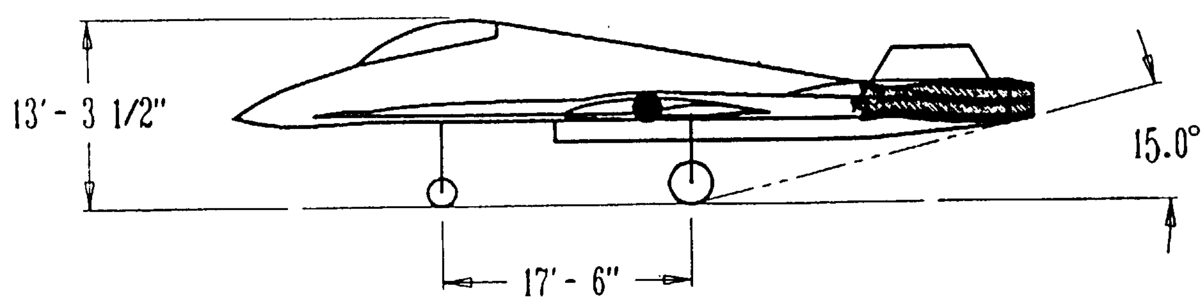
	Wing	Differential Stabilizer (one tail only)
Area (ft^2)	600.0	75.3
Span (ft)	50.0	9.12
MGC (ft)	12.44	8.56
Aspect Ratio	4.17	1.11
LE Sweep (deg)	17.8	16.8
Taper Ratio	0.5	0.5
Root Chord (ft)	16.0	11
Thickness Ratio	0.10	0.06
Dihedral (deg)	0	30
Incidence (deg)	0	variable
Airfoil	NACA 65-410	NACA 0006

Aileron Chord Ratio: 0.3c Aileron Span Ratio: 0.76 - 1.0
Flap Chord Ratio: 0.3c Flap Span Ratio: 0.24 - 0.76

	Fuselage	Cockpit
Length	55.0	7.0
Max Height (ft)	7.0	5.2
Max Width (ft)	9.0	3.6







3.1 Acceleration

Required: M = .3 to M = .5 at sea level in under 20 sec.
Achieved: M = .3 to M = .5 at sea level in 7.7 sec.

The achieved acceleration is for combat configuration:

- Half the bomb load
- Half the fuel load
- Self defense stores
- Gun and ammunition
- Full afterburner

The time to accelerate was determined by using the specific excess power plot to determine the average acceleration between the specified velocities. The basic differential equation for the acceleration was integrated between the velocities assuming a constant average acceleration to yield the time required.

3.2 Re-Attack Time

Required: < 25 seconds
Achieved: 23 seconds

The RFP requirements for the re-attack profile are:

- 4000' energy increase plus
- 360 degree turn

Using full afterburners, the A-2000 achieves a re-attack time of 23 seconds. Profile times are:

- 4000 feet energy increase: 8 seconds
- 360 degree turn : 15 seconds

The re-attack time was determined using specific excess power plots. The excess power plot for a load factor of one (steady climb) was used to determine the 4000' energy increase time (Figure 3.2.1). The excess power contours for constant turn rates were used to determine the tie required for the 360 degree turn (Figure 3.2.2).

3.3 Maximum Sustained Load Factor

Required: 4.5 g's
Achieved: 6 g's

The configuration for the maximum sustained load factor is:

- 50% bomb load
- 50% fuel load
- no flaps
- full afterburner
- M=0.6
- sea level

Contours for maximum sustained load factors are shown in Figure 3.2.3.

3.4 Maximum Instantaneous Load Factor

Required: 6 g's
Achieved: 7.5 g's (limited by structure)

The maximum instantaneous load factor for the A-2000 was calculated for the following configuration:

- 50% bomb load
- 50% fuel load
- no flaps
- full afterburner
- M=0.6
- Sea level

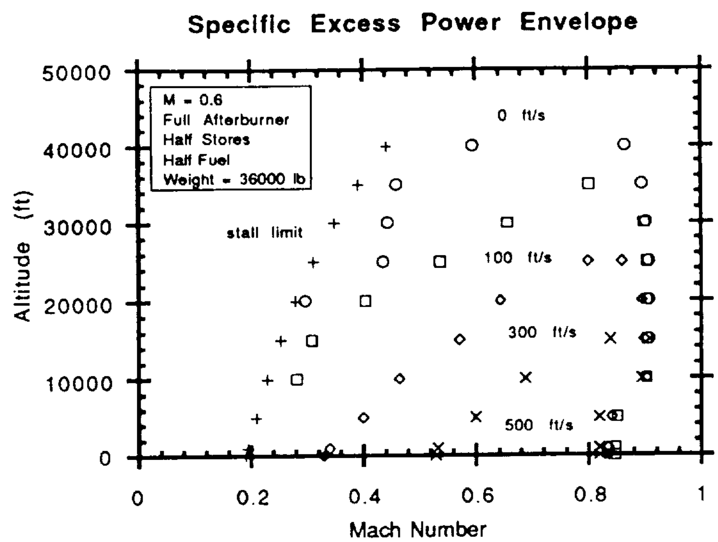


Figure 3.2.1.

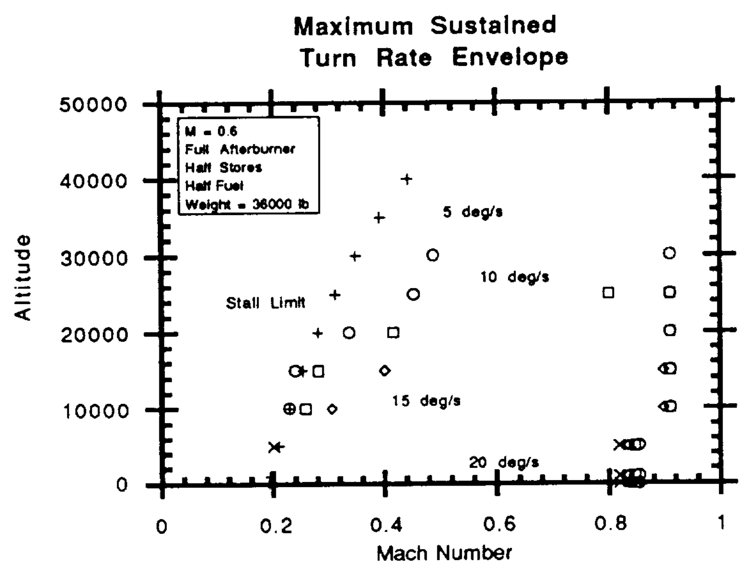


Figure 3.2.2

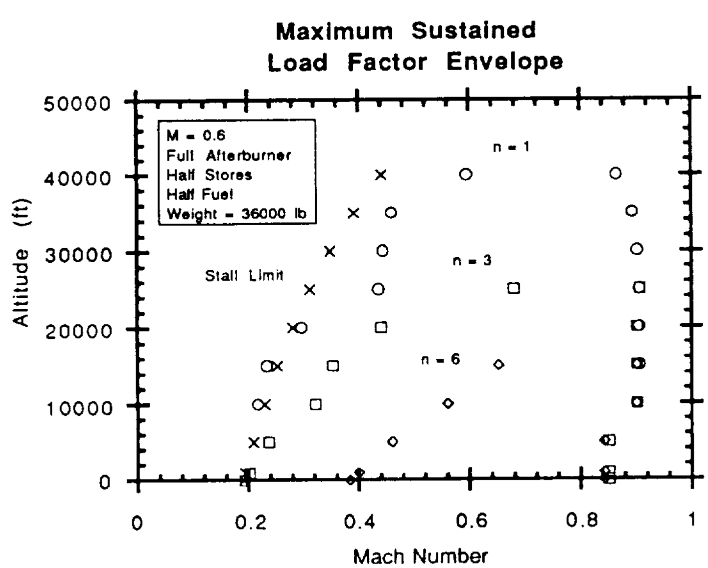


Figure 3.2.3

3.5 Range Vs. Payload

Figure 3.5.1 is a plot of the A-2000's attack radius versus payload. This plot was generated for the design mission profile which specifies:

- a sea level dash at 500 kts to the target
- two combat passes
- a sea level dash home at 500 kts
- a 20 minute loiter before landing (on reserve fuel)

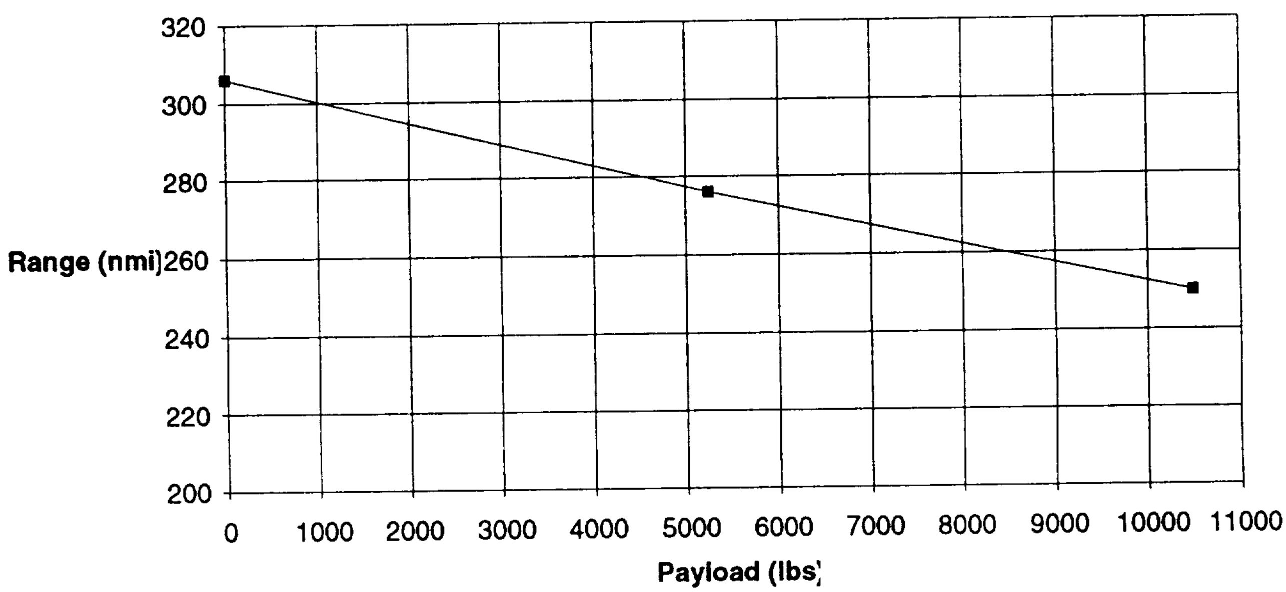


Figure 3.5.1 - Range vs Payload

3.6 Takeoff and Landing Performance

3.6.1 Take-off

The A-2000 is required to take-off within 2000 feet of ground roll on level asphalt runways at sea level altitudes. In take-off configuration:

- CL max is 1.4 with 30 degrees flap
- gross take-off weight is 46000 lbs
- wing area is 600 square feet
- thrust is 27000 lbs

Performance computations were modelled using a computer program (Appendix A6). The program integrated the basic rectilinear acceleration equation with acceleration expressed as a function of velocity until the aircraft reached 1.1Vstall. Forces involved were aerodynamic drag, rolling friction, and thrust. Takeoff rotation thrust effects were neglected.

Although the A-2000 was designed for 2000 ft ground rolls at sea level, its performance at various altitudes is also of concern. Figure 3.6.1 is a plot of the A-2000's take-off ground roll distances at various altitudes for the design takeoff weight (46000 lbs). Note that the A-2000 is capable of meeting the ground roll requirements for altitudes well above 6000 ft over sea level except for the case of 6000 ft elevation grassy runways.

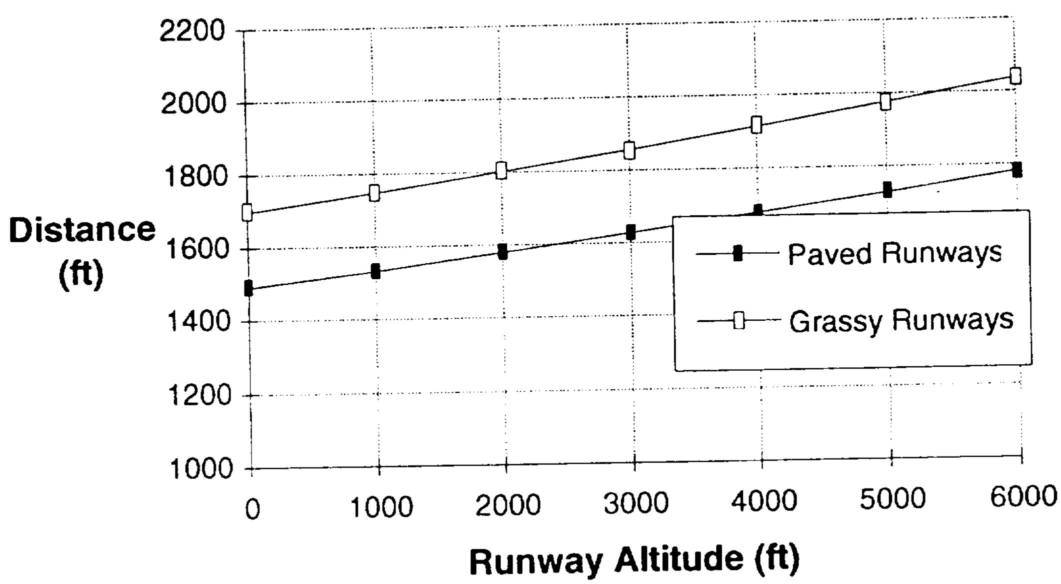


Figure 3.6.1 - Take-off distances at various altitudes

Figure 3.6.2 shows various take-off roll distances versus take-off weight at sea level. The A-2000 easily meets the required take-off distances for all operating weights. The requirements can also be met with 2000 lbs of additional payload.

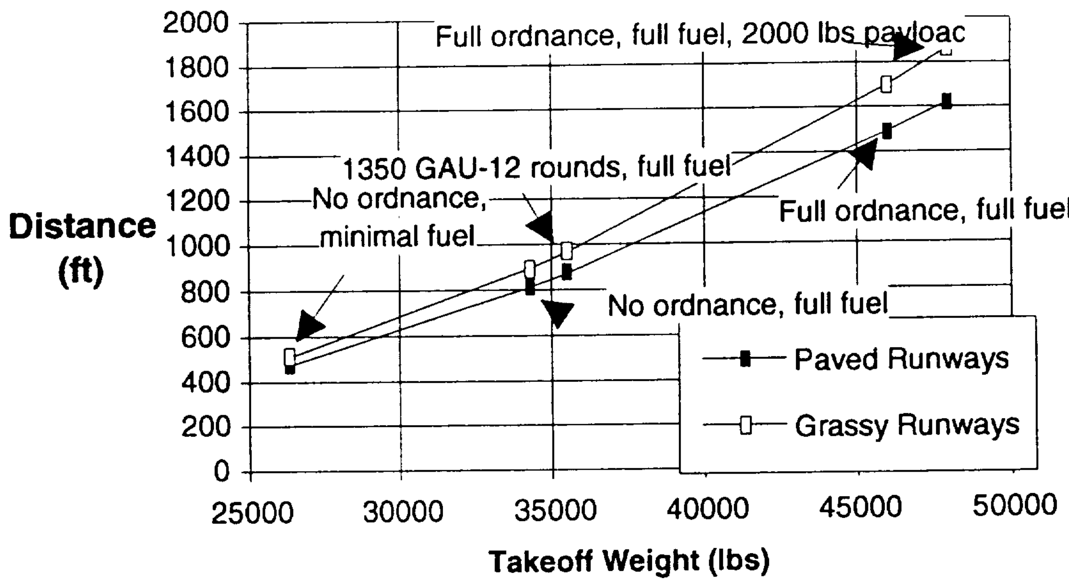


Figure 3.6.2 - Take-off distance versus weight

3.6.2 Landing

The landing performance analysis was performed using a computer program similar to the one used for the take-off analysis. The program integrated forces acting upon the aircraft once it touches down onto the runway. The touchdown velocity is computed using 1.1Vstall. Brakes were applied three seconds after touchdown. The landing requirement was more difficult to achieve. For the analysis,

- CL max was 1.6 with 45 degree flap deflection
- touchdown velocity was 177 knots
- airplane at gross take-off weight was 46,000 lbs
- rolling friction coefficient was 0.4
- idling thrust from both engines was 800 lbs

The analysis revealed that an air brake would be necessary to meet the ground roll requirement.

Landing performance at various altitudes was investigated and the results shown in Figure 3.6.3. The A-2000 can meet the ground roll requirements up to altitudes of 4000 ft above sea level. Further high altitude landing performance improvements can be made by using larger airbrakes and other devices such as drogue chutes.

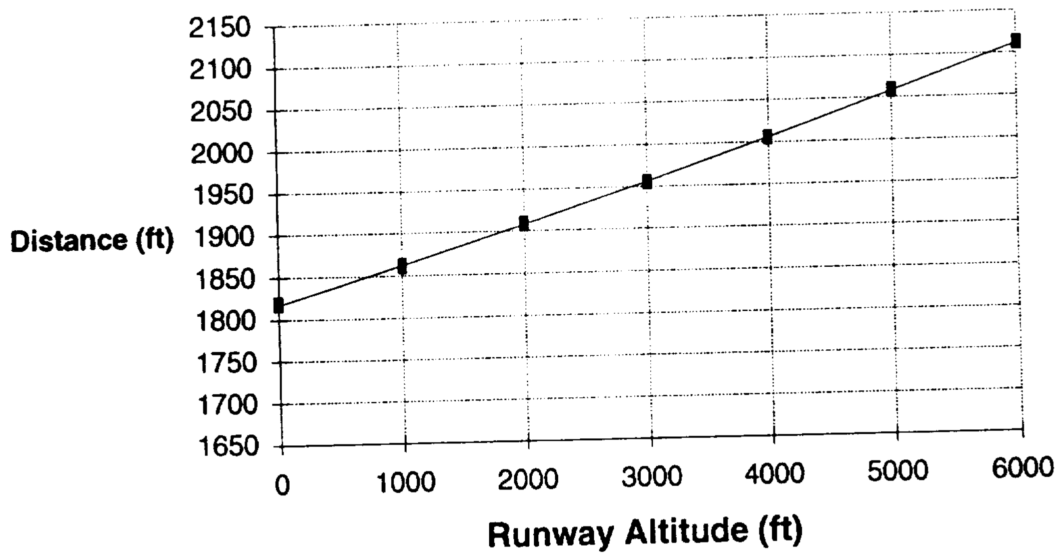


Figure 3.6.3 - Landing ground roll for various altitudes (46,000 lbs Wto)

Figure 3.6.4 shows various landing roll distances at various landing weights. Landing with no ordnance and low internal fuel the aircraft can land in 1150 ft on paved runways at sea level. The normal operational landing configuration would be:

- less than half the total internal capacity of fuel
- no bombs
- half the GAU-12 rounds
- aircraft weight around 31,500 lbs
- a landing ground roll less than 1450 ft

A worst case scenario with the aircraft landing at gross take-off weight plus an additional payload of 2000 lbs yields a landing ground roll distance of 1882 ft.

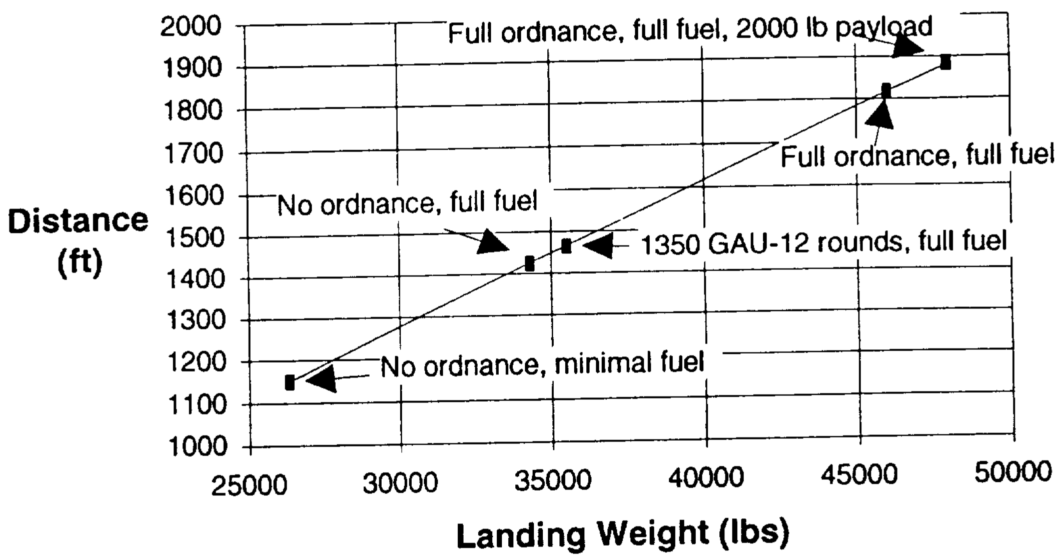


Figure 3.6.4 - Landing roll distances for various touchdown weights at S.L.

3.7 Fuel Consumptions

Table 3.7.1 contains the A-2000 fuel weights for the three design missions. The Hi-Low mission used the full internal fuel capacity as determined by the design mission analysis. The additional fuel is used during a sea-level loiter phase before the 100 nmi dash.

The ferry mission requires over 11,500 lbs of fuel. This is for a cruise altitude of 35,000 ft at Mach 0.8. Two 300-gallon wing tanks are used which result in a ferry range of 1505 nmi.

Best cruise Mach and altitude:

- M = 0.8
- h = 35,000 ft

Mission	Radius (nmi)	Fuel Weight (lbs)
Design	250	7664
Hi-Lo	250	7664
Ferry	1500	11566

*Ferry mission is one way.

Table 3.7.1 - Fuel Requirements

4.0 Preliminary Sizing

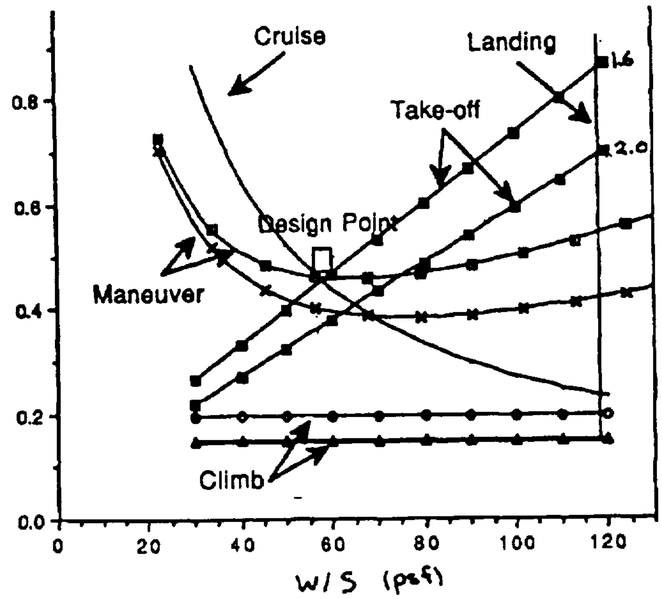


Figure 4.1.1 - Thrust to Weight Vs Wing Loading

Figure 4.1.1 shows the preliminary sizing plot used to size the A-2000. Thrust to weight and wing loadings are plotted for take-off, landing, cruise, climb, and maneuver. The preliminary design points at gross take-off were:

- Wing loading: 60 psf
- Thrust-to-weight: 0.50

Later analysis and research indicated a higher wing loading and smaller visual/radar signature would provide substantial gains in ride quality and survivability[2]. The resulting design points were:

- Wing loading: 76 psf
- Thrust-to-weight: 0.59

5.0 Configuration - Selection/Justification

5.1 Design Drivers

The selection of a suitable configuration for the close air support role involved many, often conflicting, considerations. The primary design drivers that relate to the mission performance of the aircraft are (no priority is implied by the following list):

- Survivability
- Cost
- Ordnance capacity
- High sortie rate capability
- Visibility
- Maneuverability
- High speed/low altitude handling qualities
- Short takeoff and landing capability

5.2 Initial Configuration Selection

A variety of fixed wing and rotary aircraft configurations were initially investigated as possible candidates. It became immediately apparent that conventional rotary aircraft could not fulfill the mission specifications. This was primarily due to the lack of high speed cruise capability. Furthermore, the accelerations and high lift capability necessary would have imposed considerable design challenges. Solutions such as the X-wing aircraft may be possible, but not without serious cost penalties.

Of the variety of fixed wing configurations possible, all but the conventional (tail aft), canard, and flying wing were quickly eliminated for reasons varying from high cost due to unconventionality or survivability. The three candidates were then evaluated from the standpoint of ease of adaptability to the requirements. The evaluations are presented as follows:

	Conventional	Canard	Flying Wing
Short Takeoff/Landing	Good	Good	Good
Structural Simplicity	Good	Moderate	Very Good
Maneuverability	Good	Very Good	Questionable, but possibly good.
Low altitude/high speed ride quality	Good, but depends on wing loading, avionics.	Good, but depends on wing loading, avionics.	Poor, due to low wing loading.
Maintainability	Varies depending upon design	Varies depending upon design	Good, due to large surface area for access.
Payload carrying capability	Good	Good	Very good due to high aerodynamic efficiency.
Visual/Radar signature	Moderate	Moderate	Good
Cost	Very Good	Good	Poor, due to increased R&D costs.

Table 5.2.1 - Configuration Evaluation

5.3 The First Configuration - The Flying Wing

Initial evaluations leaned toward the flying wing configuration due to its high aerodynamic efficiency (i.e. low drag, high payload fraction), structural simplicity, and low visual signature. The configuration was later scrapped due the following problems:

- Higher than hoped for drag
- Cannon gas ingestion problems
- Low pilot visibility
- Control surface washout at high angles of attack
- A re-evaluation of design drivers emphasizing low cost
- Questionable trim and maneuver capability with one elevator damaged

5.4 Revised Configuration

All indicators of suitability pointed toward a more conventional wing/fuselage/longitudinal control surface combination. As a result of these indicators, the canard and tail aft designs were again explored. The conventional tail aft configuration was selected for cost and maintainability purposes. Table 5.4.1 shows the configuration tradeoffs and the resulting configuration selections (outlined).

Wing Position			
	Low	**Mid**	**High**
Drag	Varies, depends on the type of blending used.	Varies, depends on the type of blending used.	Varies, depends on the type of blending used.
Ordnance/Ground Maintenance	Good, weapons are loaded at ground level and wing inspection can be made at eye level.	Moderate, weapons require a lifting device to load and wing inspection is more difficult.	Poor, weapons are very difficult to load and inspections and maintenance require ladders.

Number of Engines		
	1	**2**
Cost	Very good	Moderate
Survivability (engine damage)	Poor	Good
Maintainability	Very good	Moderate

Engine Position			
	Within Fuselage	**Under Wing**	**Over Wing**
Survivability	Good, the fuselage can provide some degree of protection, especially if armor is used.	Poor, engines are exposed and there's excessive surface area to armor.	Very good, the wing and fuselage serve as protection from ground fire.
Engine Out Control	Good, engines are typically close to the aircraft centerline.	Poor, engines are far away from the centerline and substantial rudder control power is required.	Poor, engines are far away from the centerline and substantial rudder control power is required.
Maintenance	Depends on fuselage geometry, generally moderate.	Very good, there's ample surface area to work around and access the engine	Good, ample surface area, but engines are higher and therefore more difficult to reach.
Drag	Good, there's little additional drag contribution due to the engines.	Poor, engine pylons and nacelles may contribute substantial drag penalties.	Poor, engine pylons and nacelles may contribute substantial drag penalties.

Tail Disposition			
	Cruciform	**Conventional**	**V-Tail**
Survivability	Poor, the intersection between the horizontal and vertical surfaces is particularly vulnerable.	Good, this configuration offers the highest degree of redundancy.	Moderate, less redundancy than the conventional, but there's typically less surface area to act as a target.
Visual/Radar Signature	Poor	Poor	Good
Drag	Poor	Moderate	Good
Weight	Moderate, structures must be heavier.	Good, light structure.	Very good, smaller surfaces and less structure.

Inlet Position (*depends on engine position)			
	Low	**Mid**	**High**
Foreign Object Ingestion	Poor	Good	Very Good
Pitch/Yaw Blanking	Very good, flow is maintained during positive g's and yaw.	Good, flow is main-tained during positive g's.	Moderate, depends on placement relative to wing/fuselage.

Table 5.4.1 - Configuration Selection Tradeoffs

5.4.1 Wing Position Selection

The low mounted wing was chosen over the mid and high mounted wings primarily for structural and ground maintenance reasons. The low and high wings both have structural benefits in that spars can run through and join the wing halves. Mid wings typically terminate the spars at the frame. This requires heavy reinforcing of the fuselage structure at the wing root sections. The spars in a mid wing may be allowed to run through the fuselage, but this interferes with the internal volume of the aircraft. The choice of the low wing benefits the structure without sacrificing internal volume.

The low wing is the optimal configuration from the ground maintenance point of view. Bombs may be loaded with little elevation requirements, and wing inspection and maintenance can be performed on the ground.

5.4.2 Number of Engines Selection

From a cost and maintenance perspective, the single engine configuration is clearly superior. However, the high threat environment that a close air support aircraft is subject to demands that an aircraft be as resistant as possible to enemy fire. It was decided that two engines were necessary for survivability. Furthermore, smaller engines tend to be more fuel efficient than larger ones. This partially offsets the added weight and maintenance cost associated with the twin engine configuration.

A three engine configuration was considered, but the increased redundancy of a third engine was not justified by the higher cost, increased maintenance, and added weight.

5.4.3 Engine Position Selection

Four engine locations were considered, under wing, over wing, fuselage pod, and within the fuselage. Originally with the GAU-8/A, gas ingestion was of primary concern and the engine (and inlet) location were driven correspondingly. With the large amount of gas produced by the GAU-8/A, the inlet should be placed as far away from the line-of-fire as possible. Though dependent on the specific configuration, the over wing and under wing positions were optimal. However, the over wing configuration suffers from flow disruption at high angles of attack and the under wing configuration provides little engine protection from enemy fire. The Fairchild Republic A-10 utilizes fuselage pod mounted engines. Although this configuration offers several appealing features such as ease of maintenance and low gas ingestion, it was not used because it was felt that it suffers from deficiencies found in both the over and under wing positions. Flow disruption from behind the wing is a problem for high mounted pods as well as reduced protection from ground fire. Also a suitable pylon structure for a long, afterburning engine would be difficult to design.

By replacing the GAU-8/A cannon with the GAU-12, the gas ingestion problem was significantly reduced. This, combined with engine out controllability and drag considerations resulted in the engines mounted within the fuselage.

5.4.4 Empennage Selection

A V-tail empennage was selected because of potential weight and drag savings over cruciform and conventional tails. Although the V-tail suffers from a lower number of redundant surfaces, its overall size and surface area is smaller which results in a smaller target. V-tails also offer lower radar cross sections than conventional or cruciform tails as an added benefit. The V-tail is composed of full flying differential stabilizers. Although this necessitated a heavier structure, the benefits to controllability were desired.

5.4.5 Inlet Position

With the engines mounted within the fuselage, the possible inlet choices were high (such as above the wing), mid (along the fuselage), or low (beneath the fuselage). The high inlet position was ruled out because of flow interference from the wing and fuselage at high angles of attack. The mid position was eliminated to avoid gas ingestion from the GAU-12 and to avoid inlet blanking during yawing maneuvers. The inlet was placed low and below the gun line-of-fire to minimize gun gas ingestion. Upwash created by the LEX should also help to divert gun gas over the wing and away from the inlets. Unfortunately, this configuration increased the engines susceptibility to foreign object damage, especially on unprepared airstrips. To counter this, auxiliary LEX mounted inlets are used during takeoff while the lower inlets are closed off by cover doors.

6.0 Component Design

6.1 Fuselage Design

The driving requirements for the fuselage design were:

- Storage of all internal fuel
- Elevated cockpit for visibility
- Housing for the large cannon
- Minimization of cannon gas ingestion

The entire fuel supply is stored within the fuselage to expose minimal tank surface area to ground fire.

The combination of a centerline mounted cannon, leading edge strake, low wing, and low intake were chosen to minimize cannon gas ingestion. The gun gas is designed to flow along the nose until it reaches the leading edge strake region. Vortex flow along the leading edge draws the gas upwards, away from the low inlet. The fuselage design will require suitable testing (such as watertunnel and windtunnel) to verify this concept.

6.2 Wing Design

The following parameters describe the A-2000's wing:

Area	600 ft^2
Airfoil	NACA 64-410
$\Lambda_{c/4}$	13.5
λ	0.5
Geometric Twist	2° washout
Aspect Ratio	4.17
Dihedral	0°
Incidence	0.78°
Single slotted flaps	0.3c

The following criteria were considered to meet the RFP requirement:

- High lift
- Weight
- Drag divergence at dash; V=500 kts
- High speed at low altitude performance

Due to the strict RFP requirement for take-off and ground roll, a low-wing loading is desired, but handling characteristics necessitate a high wing loading. The wing area is 600 ft^2. This was found by an analysis in which ground roll distance was determined as a function of Cl and wing area. This planform area allows the A-2000 to fulfill the requirements for ground roll using the smallest possible wing without complex high lift devices. A wing loading of 76 is achieved, providing the best compromise between the conflicting requirements. By selecting a minimum size planform, survivability characteristics are accounted for. A smaller target is harder to hit. This value is approximately 18 percent lower than values for the A-10 and F-15[3]. The avoidance of complex lift devices saves cost and weight.

To obtain a favorable stall characteristic, a 2 degree washout and .5 taper ratio was incorporated using the panel method[4]. The stall was to begin far enough inboard to maintain control surface effectiveness at high angles of attack.

6.2.1 Airfoil

To meet the RFP requirements, the following airfoil design criteria were considered:

- High lift coefficient
- Drag divergence during dash: 500 kts
- Internal volume for actuators and landing gear
- Weight savings

The result was the selection of the NACA 65-410.

$cl_{max} = 1.55$
$t/c = 0.10$
$cl_{\alpha} = 0.112/deg$

Thick airfoils are used in the A-2000 to minimize weight and cost. The limiting factor was drag divergence. The result was a 10% thick airfoil section. The 10% thickness minimizes weight while meeting drag divergence and lift requirements. Minimal sweep was required due to good drag divergence properties for this thickness ratio.

6.2.2 High Lift Devices

The A-2000 uses simple, drooping, single slotted flaps to provide high lift at takeoff and landing.

Flap Geometry

- Chord ratio: 0.3
- Span ratio : 0.24 - 0.76

Single slotted, Fowler, split and plain flaps were on a complexity vs. lift increment basis. Single slotted flaps were found to be the least complex system to yield the necessary lift increments. Through reduced complexity, the A-2000 is able to operate with fewer maintenance hours per sortie. Other considerations that played a role on this choice were weight and cost.

6.2.3 Leading Edge Extension

To enhance the A-2000's high angle of attack performance, a wing root leading edge extension (LEX) is used. The LEX provides a strong vortex flow region over the inboard part of the wing at high angles of attack. This flow energizes the boundary layer to prevent flow separation and stall. Gains in maneuvering qualities and safety at low altitudes result from the reduced separation behavior. This helps to increase survivability by reducing pilot workload necessary to control the aircraft in a demanding combat environment. The LEX also enhances maneuverability by providing a destabilizing effect due to a forward shift in the aerodynamic center. Reference 5 was used as a guide in selecting LEX size.

6.3 Empennage Design

The driving design drivers for the empennage were:

- Adequate control area - including during engine out
- Minimal drag

Figure 6.3.1 shows the resulting tail planform design:

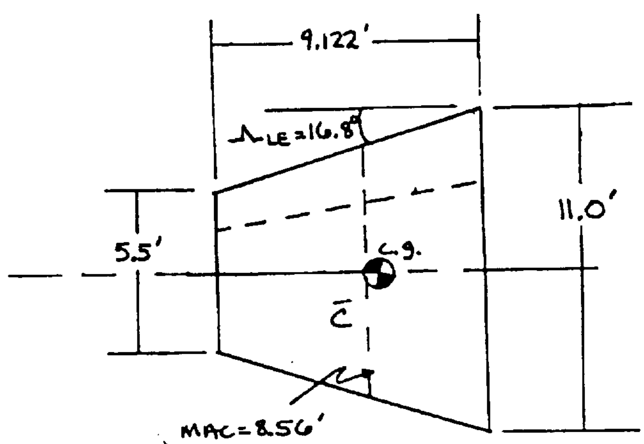


Figure 6.3.1 - Tail planform design

The following parameters describe the A-2000's empennage:

Type	Full Flying V-tail
Dihedral	30°
Horizontal Projected Area	65 ft^2
Vertical Projected Area	37.5 ft^2
Airfoil	NACA 0006
Aspect Ratio	1.11
Quarter Chord Sweep	8.57 degrees

The horizontal projected area was chosen to satisfy longitudinal stability requirements[6]. A longitudinal X-plot was used to determine the proper size to achieve a static margin of five percent. One engine out control criteria were used to determine the vertical projected area required. The vertical projected area of the A-2000's tail satisfies the directional stability guidelines presented in Reference 6. Table 6.3.1 shows that the empennage volume coefficients for the A-2000 compare to other fighter and attack aircraft.

	V_h	V_v
A-10	0.41	0.06
F-15	0.20	0.098
F-16	0.30	0.094
A-2000	0.31	0.044

Table 6.3.1 - Empennage Volume Coefficients

6.4 Propulsion System Integration

6.4.1 Overview

Figure 3.1 shows the engine installation in the A-2000. The A-2000 utilizes the following engines:

- 2 Augmented low bypass (1.8) turbofan engines
- 14,700 lbs thrust per engine (sea level, not installed)
- 2168.2 lbs weight per engine
- 147" total length

The engine inlets have the following characteristics:

- Low mounted (beneath main wing)
- Hemispherical inlet shape (1.5 ft. radius)
- Auxiliary inlet doors for take-off (strake mounted)
- Moderate divergence half angle (3.75 degrees)
- Moderate length (21 ft)
- 96% total pressure recovery (sea-level cruise)

Special considerations are:

- Inlet capture area is a compromise between takeoff airflow requirements and cruise spill drag constraints
- Gun gas ingestion is reduced by mounting inlets low and beneath the wing
- APU/hydraulic starter system allows aircraft to operate on remote airfields with minimum ground crews
- Low mounted inlets offer accessibility and ease of engine maintenance/removal

Foreign object ingestion (FOI) from unprepared fields is reduced through:

- Auxiliary inlet doors used for take-off
- Main gear located behind inlets
- Inlets located more than 2 inlet diameters above the ground
- Mud flaps are used on the nose gear
- Nose gear placement exceeds minimum angular criteria of 12 degrees

The table in Appendix A2 shows how the selected engine compares with data for the F-404 and F-100 engines. The selected engine is lighter, shorter, and smaller in diameter than either the F-404 or F-100 while employing a higher bypass ratio and thereby increased fuel efficiency. The nominal thrust level of 14,700 lbs is lower than either engine, but is thoroughly sufficient for the performance requirements of the A-2000. The "rubber" engines were selected over the two existing engines because of the higher efficiency and lower thrust levels required.

6.4.2 Engine Inlet

In designing the engine inlets the following factors where of primary concern,

- Maximization of pressure recovery
- Minimization of cannon gas ingestion
- Minimization of foreign object ingestion (FOI) on unprepared runways
- Minimization of spillage drag at cruise

Optimization of pressure recovery requires minimizing both frictional losses and boundary layer separation losses. The A-2000 inlet design represents a compromise by incorporating an inlet of moderate length (21 ft) and moderate diffuser half angle (3.75 degrees). Reference 7 suggests that a diffuser half angle greater than seven degrees would lead to large separation losses. The design results in a pressure recovery of 0.96 at the cruise flight condition of 500 kts at sea level. The inlet design benefits from a compression component attributable to the low inlet configuration.

Ingestion of gases from the GAU-12 cannon is a primary consideration for this aircraft. The low mounted inlet design philosophy is based upon pictorial evidence of gun out-gassing from the A-10 . Without a gas diverter plate the GAU-8 gun gas trailed behind the line of fire. In the presence of wing upwash, the gas flowed over the wing and into the high mounted engines. This phenomenon resulted in the addition of a large gas diverter plate to force the gas to flow beneath the fuselage. On the other hand, the A-2000 low mounted inlet design takes advantage of the natural tendency for the gas to flow upward in the presence of the wing upwash. Furthermore, the LEX will increase vorticity in the wing area region which should enhance this effect.

Low mounted inlets tend to be troublesome with regard to foreign object ingestion from unprepared runway surfaces. This problem is circumvented in the A-2000 by employing auxiliary inlet doors on top of the strake. The auxiliary inlet is 7.0 ft^2, twice the main inlet area. During take-off from unprepared runways the auxiliary doors are completely opened, while the main inlets are shut off by a door. The pilot can elect to leave the inlet doors open on prepared runways for increased diffuser performance at takeoff.

Several other precautions were taken to reduce FOI problems. First, the inlets are located forward of the main gear. Next, the inlets are more than 2 inlet diameters above the ground as recommended in Reference 7. Additionally, a mud flap will be used to minimize FOI from the nose gear. The inlet placement exceeds level B criteria which recommends that the angle between the nose wheel and inlet (measured relative to the horizontal) be at least 12 degrees[11]. The angle for the A-2000 is shown in Figure 6.5.2 as 24.5 degrees.

Figure 6.4.1 shows the internal contour of the inlet duct for various fuselage stations. The inlet begins as a straight hemisphere of 1.5 ft radius, diverging at a diffuser half angle of 3.75 degrees to become a full circle of 2.7 ft diameter before entering the fan.

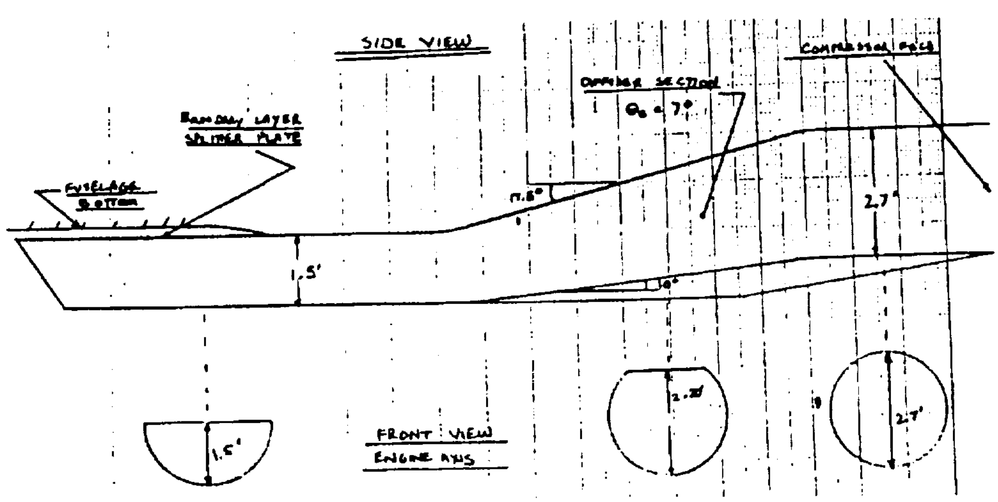


Figure 6.4.1 - Engine Inlet Design

The inlet sizing procedure involved determining the required thrust per engine and the corresponding airflow and power lever angle. Figure 6.4.2 shows the installed thrust profiles for various Mach numbers at sea level. Based upon cruise drag computations (Appendix A3), each engine must supply 4260 lbs of thrust at Mach 0.76. This is accomplished at a power lever angle setting of 58%, as shown.

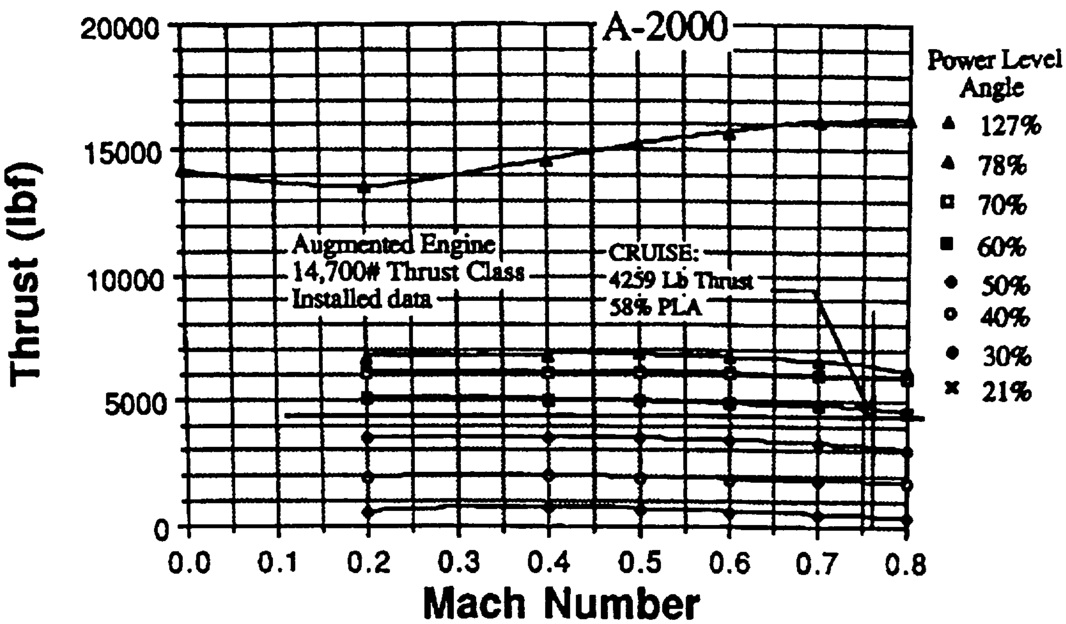


Figure 6.4.2 - Thrust at sea level

Figure 6.4.3 shows the engine airflow requirements versus Mach number. Flying at Mach 0.76, 58% power lever angle, the engine requires 185 lbm/sec of air. This airflow requirement is met with a capture area of 2.86 ft^2 (Appendix A3). Sizing the inlet for cruise would minimize excess spillage, but would severely limit the air flow for take-off. Furthermore, sizing the inlet for take-off conditions would incur significant spillage drag (up to 33% of the total drag) at cruise. A capture area of 3.5 ft^2 was selected as a compromise to both conditions.

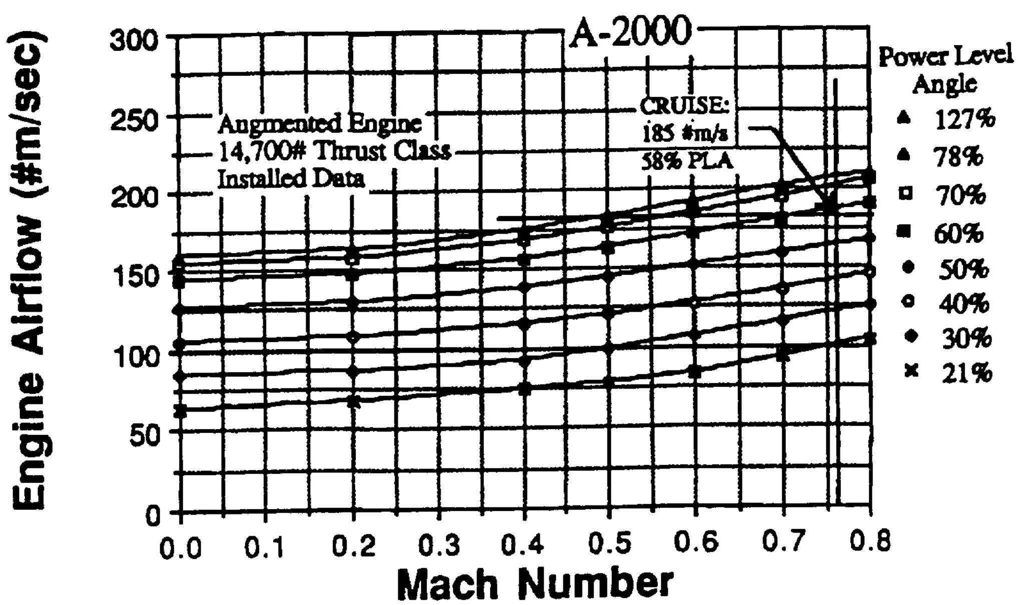


Figure 6.4.3 - Engine airflow requirements

Table 6.4.1 contains the demand capture area for the engine during critical flight conditions of the design mission. The data represents full throttle acceleration to cruise speeds. The inlets would be grossly oversized for cruise if A_c, the capture area, was sized to 10.109 ft^2. To conserve fuel by reducing drag during cruise, the inlet was sized to Ac = 3.5 ft^2, slightly above the engine demand area for cruise, A_∞. The engine is starved when $A_c/A_\infty < 1$. The excess air is spilled when $A_c/A_\infty > 1$. By doubling the inlet area with auxiliary doors, the engine is only starved for $M_\infty = 0.2$. The engine will accelerate the freestream air somewhat to obtain the required mass flow rate for take-off. This will reduce inlet efficiency during the short take-off phase, while optimizing the efficiency for cruise.

Mach	A_∞ (ft^2)	A_c/A_∞ (inlet only)	A_c/A_∞ (aux. doors)	Power Lever Angle
0.2	10.109	0.35	0.7	127%
0.4	5.416	0.65	1.3	127%
0.6	3.816	0.92	1.83	127%
0.7	3.569	0.98	1.96	127%
0.76	2.86	1.22	2.45	58%

Ac = Capture (cowl) Area, A_∞ = Engine Demand Area

Table 6.4.1 - Demand Capture Area for Single Engine

6.4.3 Engines

The A-2000 engines represent a scaled version of the "rubber" engine data supplied for the competition (Appendix A5). The engines have been sized according to thrust requirements for take-off. Scaling was accomplished via scaling parameters provided with the engine data. The results of these calculations are shown in Appendix A3. A weight savings of 1078 lbs per engine is obtained by using augmented engines. That is, a dry engine with equivalent static thrust must be sized up and it will weigh 1078 lbs more than an augmented version capable of the same thrust. The augmented engines are slightly longer than non-augmented, however they are smaller in diameter and require less overall space. More importantly, a dry engine capable of the necessary thrust level for take-off would provide unnecessarily high thrust levels during cruise and loiter, where it is desirable to operate the engine in its most efficient setting. The augmented engine provided an acceptable power envelope while operating at low specific fuel consumptions (TSFC=0.8) during cruise.

Figure 6.4.4 shows the engine installation losses for various Mach numbers. The curves show that the minimum take-off requirement of 13,500 lbs per engine is achieved for a full throttle acceleration to cruise speed. The engines were scaled through an iterative process until take-off requirements were met. Appendix A4 contains sample calculations of installed thrust for the Mach 0.2, sea level flight condition.

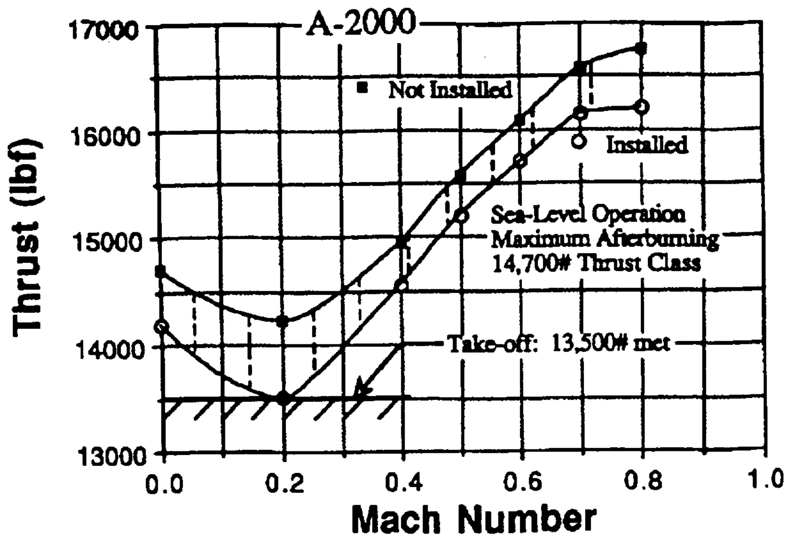


Figure 6.4.4 - Engine installation losses

6.5 Landing Gear

The A-2000 is equipped with a conventional retractable tricycle type landing gear. This configuration was chosen over the tailwheel configuration because it provides better visibility over the nose during ground operation and better ground maneuvering characteristics. Also, center of gravity changes during the course of flight would have a greater effect on ground roll stability with a tailwheel configuration and could produce dangerous handling characteristics on the ground. Figure 6.5.1 from depicts the landing gear configuration chosen for the A-2000.

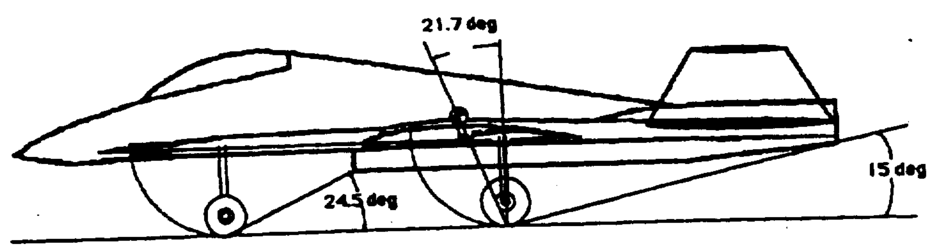


Figure 6.5.1 - A-2000 Tricycle Landing Gear

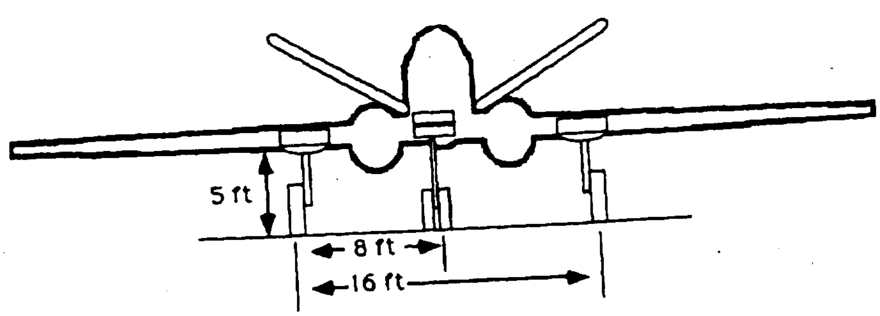


Figure 6.5.2 - Landing Gear Disposition

6.5.1 Main Gear

The two single wheel main gear units, as shown in Figure 6.5.3 (Reference 8) are positioned 8 feet from the centerline of the airplane and are situated under the wing box as shown in Figure 6.5.2. The wide stance of the main gears provide for lateral stability. At this position, there is a 22 degree angle between the main gear contact point and the center of gravity to provide for longitudinal stability, and a tail clearance angle of 15 degrees. The main gear retracts forward and rotates 90 degrees into the leading edge of the wing during flight. This was done to utilize the unused space in the wing box. Also, the landing gear doors will be blistered to provide extra room for the strut fork.

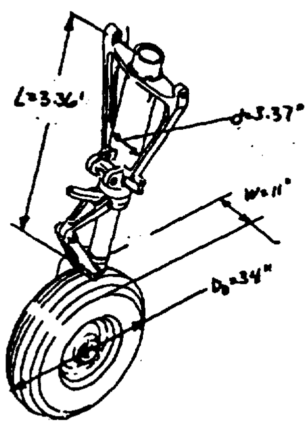


Figure 6.5.3 - Main Gear

6.5.2 Nose Gear

The twin wheel nose gear, as shown in Figure 6.5.4 (Reference 8), is mounted beneath the cockpit and rotates 90 degrees forward into the fuselage next to the gun for flight. The two wheels are needed to carry a dynamic load of 17,480 lbs. A critical angle of 24.5 degrees discourages foreign object damage (FOD) to the low mounted engine inlets. Splash guards help to reduce FOD.

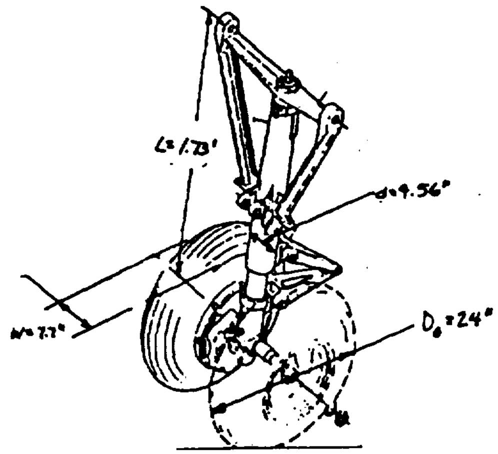


Figure 6.5.4 - Front Gear

6.5.3 Tire Selection

The method in Reference 8 was used to determine the tire sizes for the A-2000. The tire selection was based on the following criteria:

- Minimum tire pressure for landing on unpaved surfaces
- Minimum tire size and weight
- Maximum landing velocity

During combat, takeoff and landing on sand or grassy surfaces may be necessary. Low tire pressures are needed to prevent tire failure due to local indentation. Table 6.5.1 lists pertinent tire dimensions for both gears. The high pressures were necessary due to a maximum takeoff velocity of 180 mph.

	Main Gear	Nose Gear
Max vert. static load	18,400 lbs	9200 lbs
Tire size	34" x 11" TL	24" x 7.7" TL
Ply rating	20	16
Pressure	165 psi	165 psi
Max rotation speed	200 mph	210 mph
Tire weight	77 lbs	27.5 lbs
Manufacturer	B.F. Goodrich	B.F. Goodrich

Table 6.5.1 - Tire specifications

Although tire sizes and inflation pressures of the A-2000 are higher than that recommended for hard sand and grass (Reference 8), they are lower than other fighters in its weight class (A-10, F/A 18, F-14)[3]. This gives the A-2000 better rough field performance. Table 6.5.2 compares various tire specifications of other aircraft with that of the A-2000.

	A-10[3]	F/A-18A[3]	F-14[3]	A-2000
weight	47,094 lbs	44,500lbs	58,521 lbs	46,000lbs
M.G. tire size	36" x 11"	30" x 11.5"	37" x 11.5"	34" x 11"
M.G. pressure	200 psi	245 psi	245 psi	165 psi
N.G. tire size	24" x 7.7"	22" x 6.6"	22" x 6.6"	24" x 7.7"
N.G. pressure	90 psi	270 psi	270 psi	165 psi

Table 6.5.2 - Aircraft Comparison Data

6.5.4 Retraction Sequence

Figure 6.5.5 (Reference 8) shows the retraction sequence for both the main gears and the nose gear. As stated earlier, the gears retract forward and rotate 90 degrees to utilize as little space as possible. This configuration is ideal if the hydraulics are disabled and the gear must free-fall into the locked position, because gravity and the airstream help extend the gear[3]. In the case of a belly landing, the engine inlets and the armor plating beneath the fuselage will protect the fuel tanks. The struts will be simple, rigid legs with slight suspension for rough landings, much like that of the A-10. This will keep the complexity and the cost low.

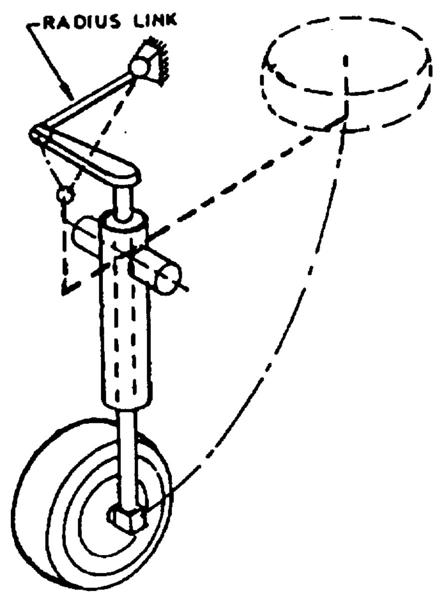


Figure 6.5.5 - Retraction Sequence

7.0 Structures/Materials

Figure 7.0.1 shows the V-n diagram used in the structural design.

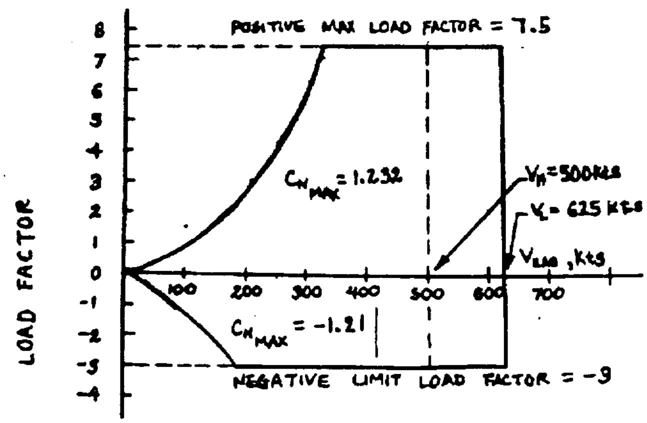


Figure 7.0.1 - Velocity - Load Factor Plot

7.1 Material Selection

The fuselage and wing structures are composed of 2024-T3 lithium aluminum. This material was chosen for its low weight, 10-20% lighter than conventional aluminum alloys, and high strength, modulus increases of 10-20%[9]. Composites were considered, however their increased manufacturing cost, low fracture toughness, and questionable battlefield maintainability prohibited their use as a primary structural material. Composite flaps and ailerons are used since these surfaces are simple in shape, easily manufactured, easily replaced, and are non load-bearing . They are composed of a Nomex honeycomb sandwich with aluminum faceplates[10]. This was selected to optimize strength to weight and high fatigue resistance because of continuous core attachment to the facing which reduces stress concentrations around fasteners. A Plexiglass canopy was selected for low weight compared to glass. It is also easier to manufacture and safer than glass. Like the wing, the empennage is constructed entirely of lithium aluminum. A honeycomb sandwich design similar to the flaps and ailerons was considered but not used due to the high loading of the tail, especially at the single supporting control arm. The landing gear are composed primarily of 4130 steel. This material was chosen since high strength was the primary driver.

7.2 Wing

The wing structural layout is shown in Figure 7.2.1. The wing is of typical rib and spar construction. A highly indeterminate spar structure was chosen and optimized for strength and weight using analytical semimonocoque theory. A large number of spars was chosen over simple spar doubling to reduce the susceptibility to structural failure when damaged from ground fire. The spars are I-beam in shape and with heights that taper with the airfoil sections. The ribs are 0.5" thick and spaced 30" apart. The upper and lower skin thickness is 0.063".

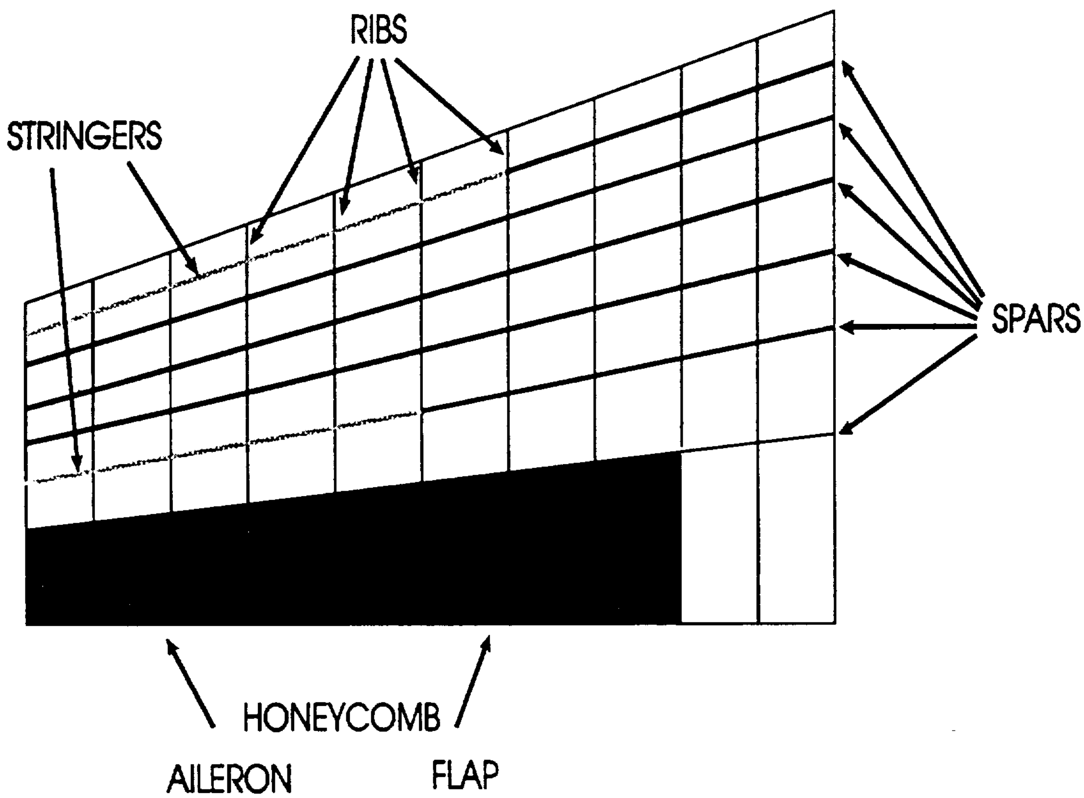


Figure 7.2.1 - Wing Structural Layout

7.3 Fuselage

The fuselage, shown in Figure 7.3.2, is also of typical construction utilizing bulkheads, longerons, and frames. The spacings of the structural members were determined using the guidelines of Reference 11. A high degree of structural synergism is attained by utilizing common bulkheads for the front landing gear, gun barrel, and pressure bulkhead, ammo drum and wing spars, wing spar and main gear, and engine and tail mounts.

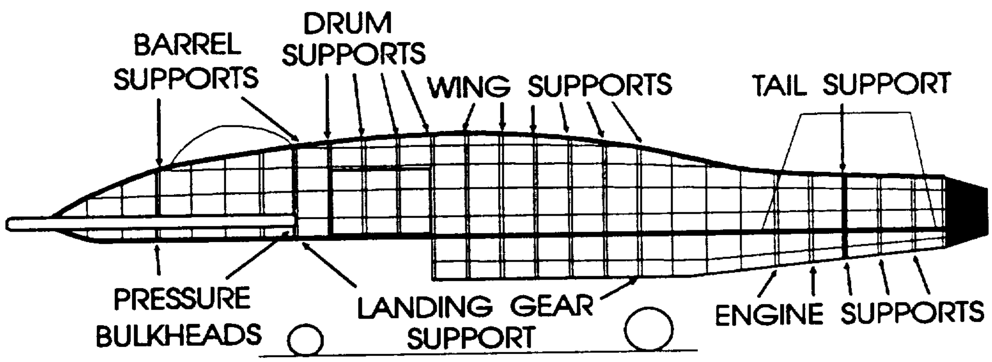


Figure 7.3.2 - Fuselage Structural Layout

7.4 Empennage

The A-2000's empennage utilizes a differential butterfly tail. The tail structure, as shown in Figure 7.4.1, is very similar to the main wing with the exception of the titanium reinforced main spar. Titanium reinforcement is required because of the high stress concentrations at the root section. This is due to the single pivot support of the differential stabilizer.

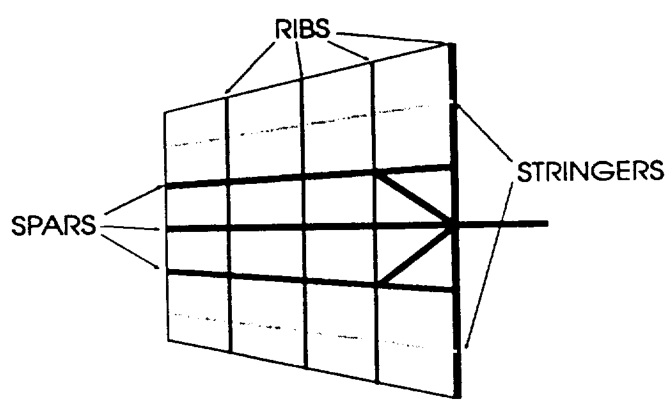


Figure 7.4.1 - Tail Structural Layout

8.0 CG/Moment of Inertia Analysis

8.1 Component Weight Breakdown

The aircraft weight was estimated using three different methods utilizing empirical equations and iteration methods[12,2,7]. Three different methods were used for comparison purposes. Having three different methods of weight estimation allowed for consistency in results. When available, actual weights took precedence over empirical methods. The following is a component weight breakdown for the A-2000:

Components	Weight (lb)	F.S. (in)	W.S. (in)	W.L. (in)	Components	Weight (lb)	F.S. (in)	W.S. (in)	W.L. (in)
Engines					*GAU-12*				
engine left	2168.2	630	-27	120	barrel/driver	269	170	-9.296	120
engine right	2168.2	630	27	120	feeding mechanism	289	250	0	120
fuel system/tanks	348.68	471.6	0	130	ammo drum	459	312	0	120
engine controls	44.69	630	0	120	*UNUSEABLE FUEL*				
APU	224	600	0	115	tank	150	472	0	115
starter	19.78	620	0	115	oil	50	684	0	115
firewall	22.19	620	0	120	*CREW*	225	250	0	140
engine mounts	66.39	615	0	120	*RACKS*				
oil cooling system	76.85	615	0	120	bomb racks:right 1	110	456	218	114
AVIONICS					bomb racks:right 2	110	456	146	114
ECM	400	140	0	120	bomb racks:left 1	110	456	-146	114
Lantirn Pod 1(Targeting)	431	425	-114	110	bomb racks:left 2	110	456	-218	114
Lantirn Pod 2(Navigation)	544	425	114	110	missile rails:left	40	504	-306	120
Instruments	133.69	200	0	157	missile rails:right	40	504	306	120
Misc. Communication/avionics	300	300	0	167	*FUEL*				
Batteries	50	100	0	130	Internal tank	7700	480	0	120
ELECTRICAL SYSTEM for USAF	494.82	180	0	120	*AMMO CARGO*	2478	325	0	120
PNEUM./HYDRAULIC	521.93	615	0	120	*ORDNANCE*				
COCKPIT					Mk-82 (20 bombs)	10100			
furnishings	179.6	240	0	135	Aim-9				
A.C./anti-icing/pressurization	284.786	630	0	110	Aim 9 left	195	507	-314	120

Table 8.1.0 - Component Weight Breakdown

•	Weight	F.S.	W.S.	W.L.		Weight	F.S.	W.S.	W.L.
Components	(lb)	(in)	(in)	(in)	Components	(lb)	(in)	(in)	(in)
oxygen system	16.9	240	0	125	Aim right	195	507	314	120
armor plating(cockpit)	800	240	0	125	External fuel	4000	470	150	108
flight controls I	500	500	0	120	300 gal Tank(left)	250	470	150	108
flight controls	500	500	0	120	300 gal Tank(right)	250	470	150	108
armor (rest)	1200	530	0	110	*LANDING GEAR*				
STRUCTURAL WEIGHT					nose gear	338.64	300	8	120
paint	204.2325	420	0	120	left gear	772.73	510	-43.2	115
planform	3782.46	480	0	120	right gear	772.73	510	43.2	115
vertical tail	933.21	660	0	140					
fuselage	5088.71	412	0	130					
inlet	334.12	490	0	100					
racks(conformal mount)	350	470	0	110					

Table 8.1.0 - Component Weight Breakdown (continued)

The component weights were combined and resulted in the aircraft weights for the design and ferry. Table 8.1.1 contains the weights as classified by military specifications

.

Weights	Design(lbs)	Ferry(lbs)
Empty (no gun)	24073	24072
Basic	25240	25240
Operating	25575	25465
Max. Take-off	45542	35159

Table 8.1.1 - Airplane Weight for Design and Ferry Missions

8.2 C.G. Analysis

Component center of gravity locations were estimated when unavailable. In computing the airplane C.G., individual component moments were summed and then divided by the summed weight [12].

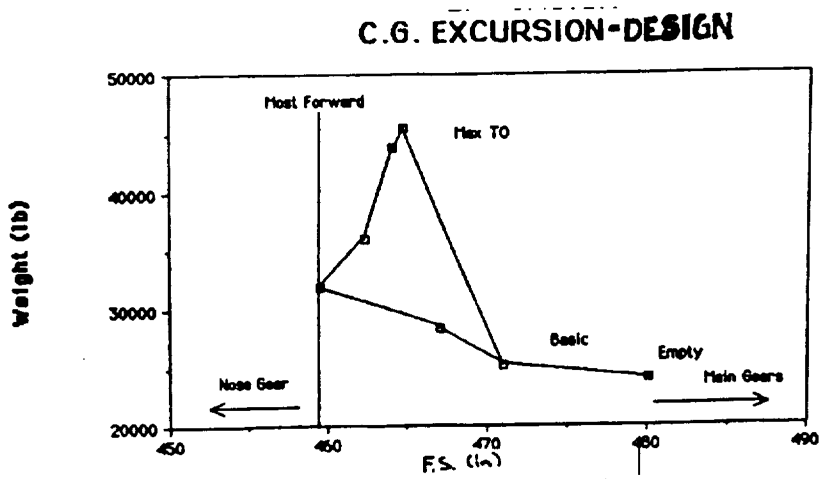
Tables 8.2.1 and 8.2.2 summarize the C.G. analysis. The fuselage reference station is10 ft in front of the nose. The butt line is the centerline of the wing. The water line is referenced from 10 feet below the centerline of the wing. Figure 8.2.3 shows the C.G. excursions or the Design/Hi-Lo and Ferry missions.

Weights	Fuselage Station(in)	Butt Line(in)	Water Line(in)
Empty	480.07	0.64	122.31
Basic	471.03	0.51	122.40
Operating	469.02	1.44	122.52
Gross	464.66	0.81	119.29

Table 8.2.1 - C.G. Locations for the Design and Hi-Lo Mission

Weights	Fuselage Station(in)	Butt Line(in)	Water Line(in)
Empty	480.07	0.64	122.31
Basic	471.03	0.51	122.40
Operating	469.07	0.51	122.55
Gross	472.08	0.37	121.08

Table 8.2.2 - C.G. Locations for the Ferry Mission



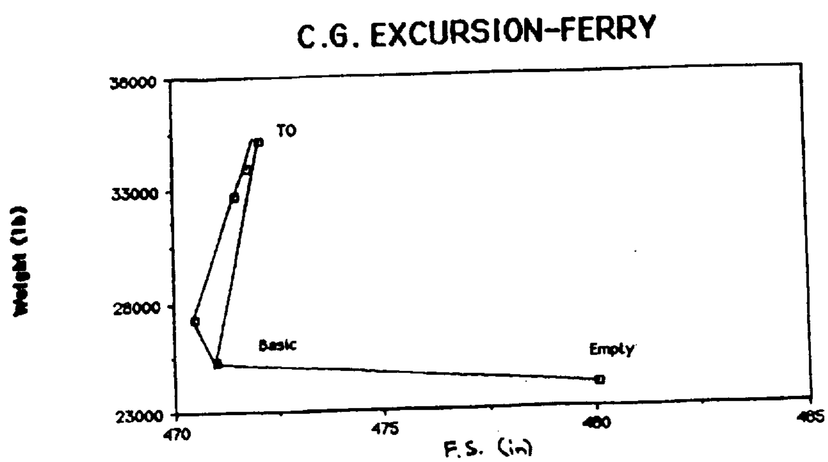


Figure 8.2.3 - C.G. Excursion Diagram

8.3 Moments of Inertia

For the moment of inertia computations, inertias of each component about its own center of gravity were not used[12]. This was justified by their small magnitudes in relation to their inertias about the aircraft cg. Table 8.3.1 contains the mass moment of inertia for the A-2000 in the design/hi-lo and ferry mission configurations.

Mass Moment	Design/Hi-Lo Mission	Ferry Mission
Ixx	63107.8	4611.05
Iyy	169439.4	94635.8
Izz	169438.97	98115.06
Ixy	-510.36	-69.70
Ixz	-24.43	-30.36
Ixy	-1675.38	-1642.29

Table 8.3.1 - Mass moment of inertias slug-ft^2

9.0 Aerodynamics

9.1 Lift Determination

Trimmed lift plot for the A-2000 are shown in Figure 9.1.1. Values for trimmed maximum lift coefficient are:

- Clmax takeoff = 1.4
- Clmax landing = 1.6
- Clmax dash = 1.0
- Clmax combat = 1.0

The trimmed lifts were determined from the methods presented in Reference 15 and 16. These methods involved determining the lift and moment curve data for individual components. This data was then combined with the incremental changes due to stabilizer deflection to obtain the trimmed characteristics.

The V-tail required special considerations for computations involving its lift behavior. Where necessary, its value of Cl_α or δ_h were modified by the cosine of the dihedral angle.

Aerodynamic center location for the wing/LEX combination was obtained by approximating it as a double-delta planform. The method used was taken from Reference 16.

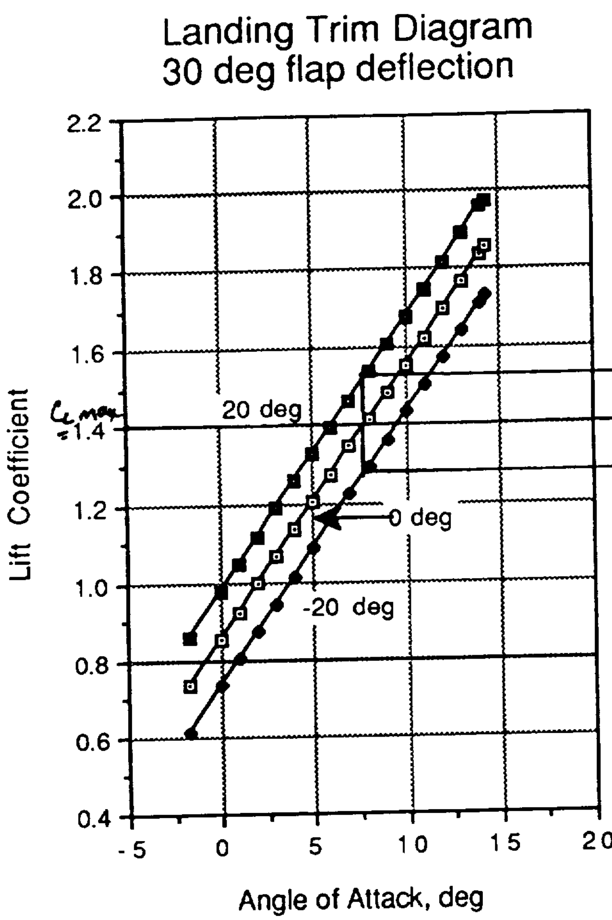
Changes in lift and moment behavior due to high lift devices were approximated using empirical methods in Reference 16.

9.2 Drag Determination

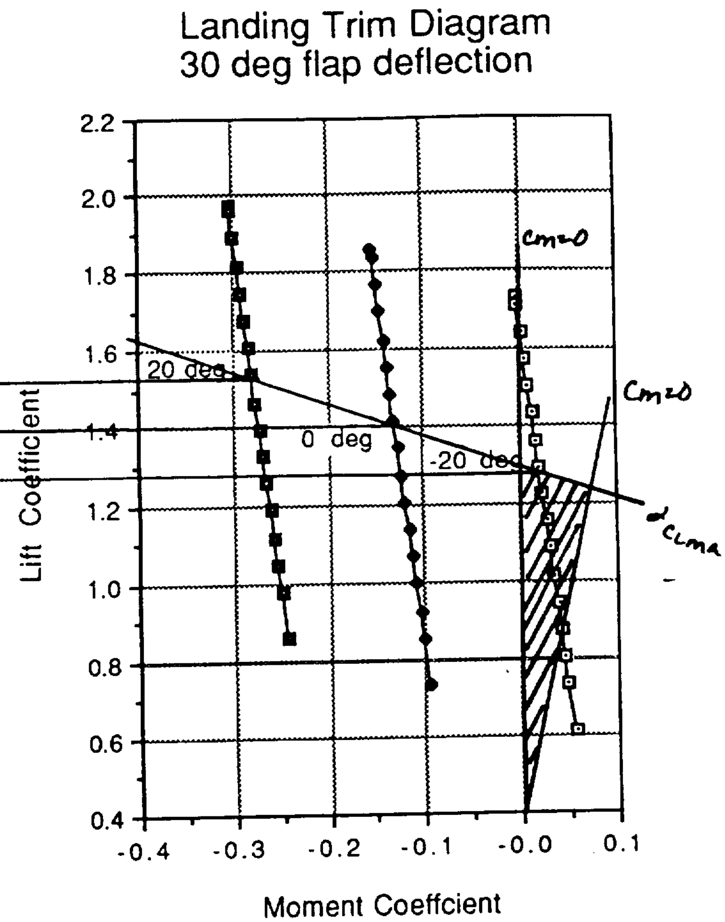
Drag polars for the A-2000, estimated from a component buildup method in Reference 13, were calculated for each phase of the design mission. Trimmed drag polars are shown in Figure 9.2.1.

Compressibility effects at high Mach numbers were determined using Reference 7. The zero lift drag behavior of the complete aircraft is shown in Figure 9.2.3.

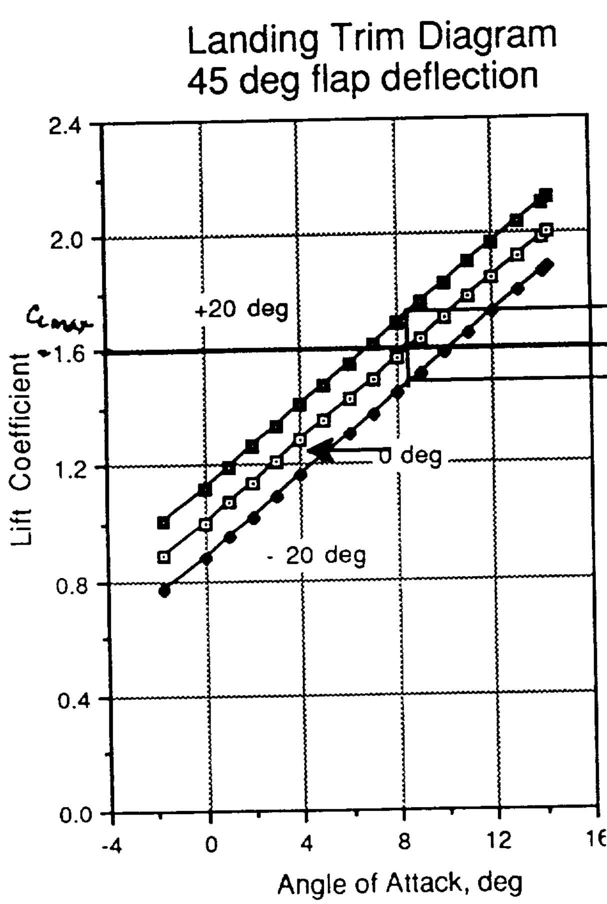
An effort to reduce zero lift drag was made by carrying a portion of the bomb load conformally on the fuselage. Information found in Reference 3 on the weapons



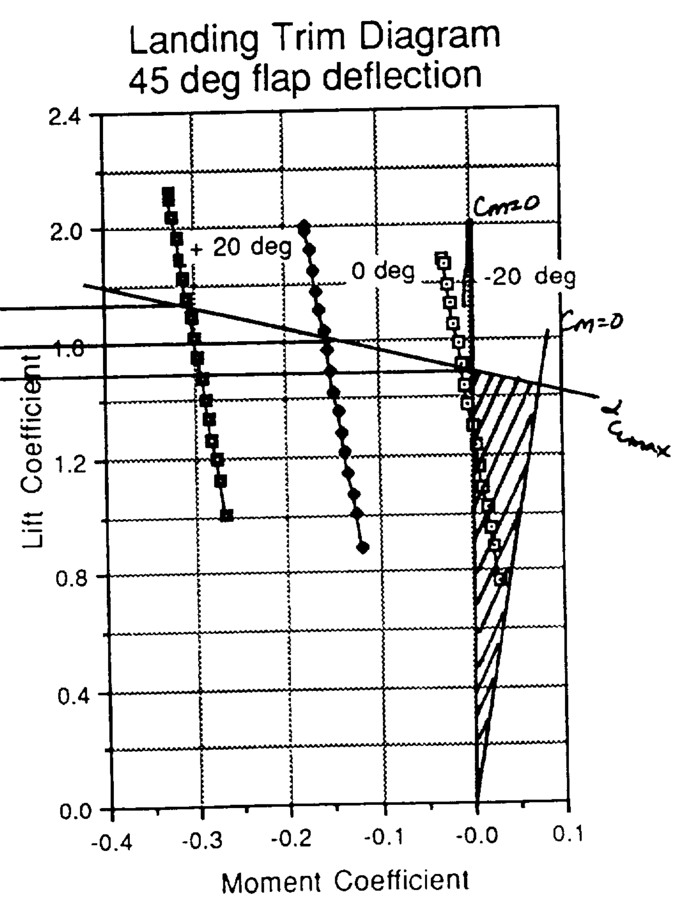
Landing Trim Diagram
30 deg flap deflection
Lift Coefficient
Angle of Attack, deg
20 deg
0 deg
-20 deg
$C_{L_{max}}$ = 1.4



Landing Trim Diagram
30 deg flap deflection
Lift Coefficient
Moment Coeffcient
20 deg
0 deg
-20 deg
Cm=0
Cm=0
$\alpha_{C_{Lmax}}$



Landing Trim Diagram
45 deg flap deflection
Lift Coefficient
Angle of Attack, deg
+20 deg
0 deg
- 20 deg
$C_{L_{max}}$ = 1.6



Landing Trim Diagram
45 deg flap deflection
Lift Coefficient
Moment Coefficient
+ 20 deg
0 deg
-20 deg
Cm=0
Cm=0
$\alpha_{C_{Lmax}}$

Figure 9.2.1

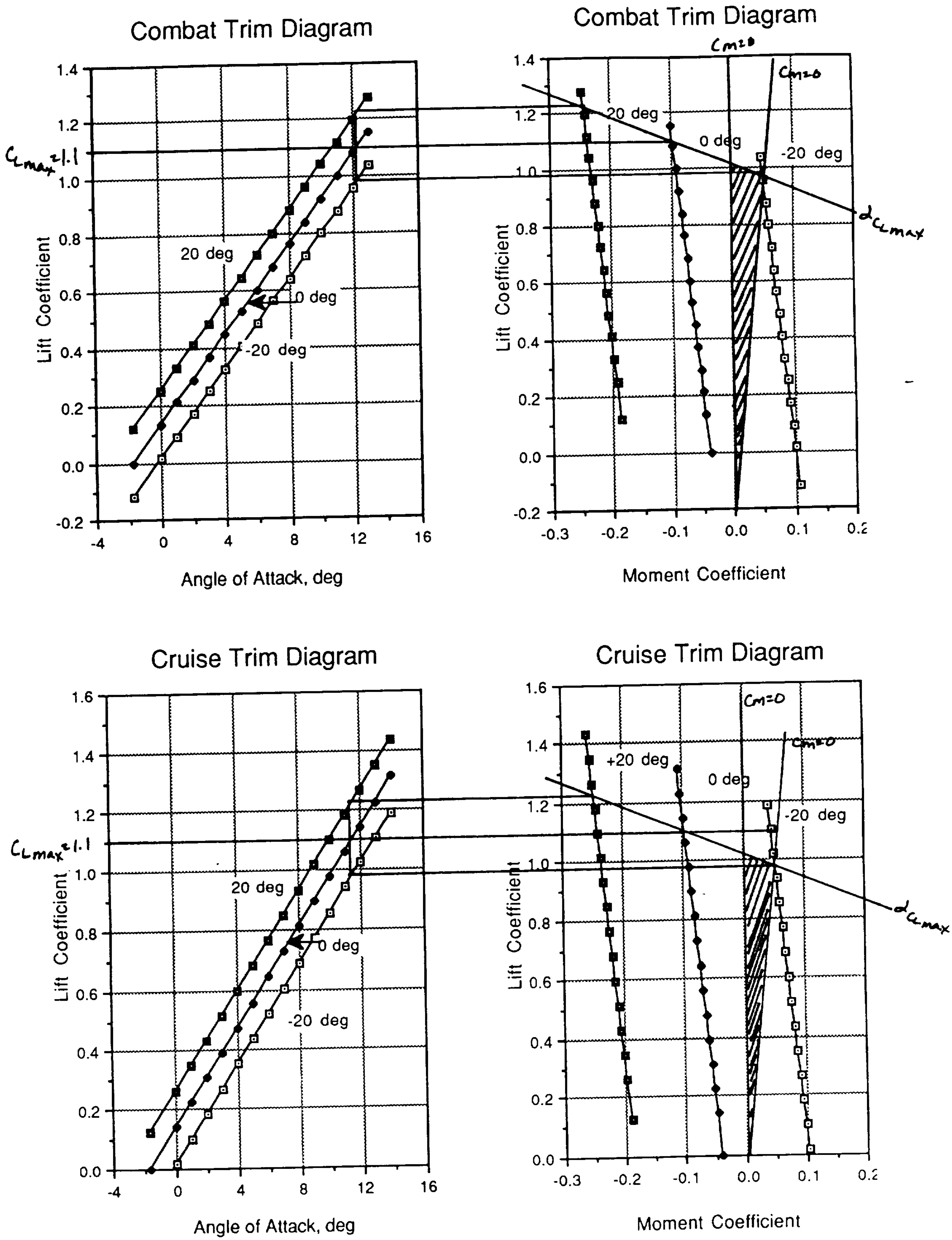


Figure 9.2.1 cont.

placement of the F-14 Tomcat indicated that this could lead to a substantial drag reduction. Figure 9.2.2 (taken from Reference 14) shows the equivalent parasite areas for several fighters without stores. The A-2000, with full external stores, is comparable to these aircraft in clean configurations.

Wetted Areas	
Wing (exposed)	800 ft^2
fuselage & canopy	1132 ft^2
tail	118 ft^2
stores & racks	420 ft^2
Total	2540 ft^2

Table 9.2.1 - Component Wetted Areas

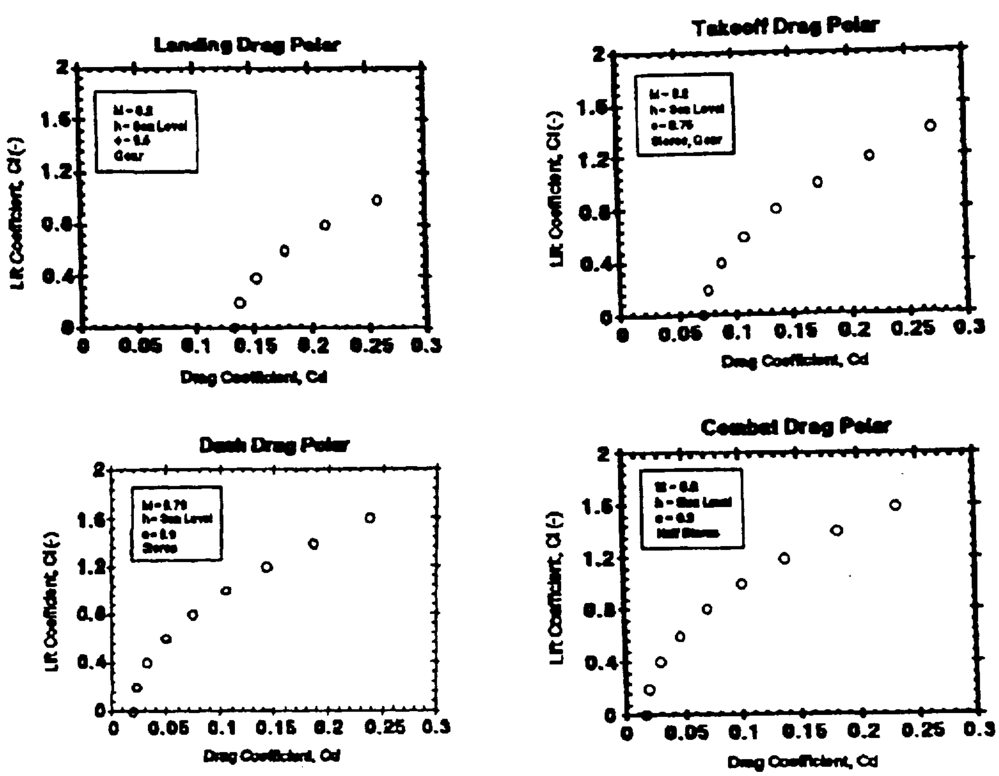


Figure 9.2.1 - A2000 Drag Polars

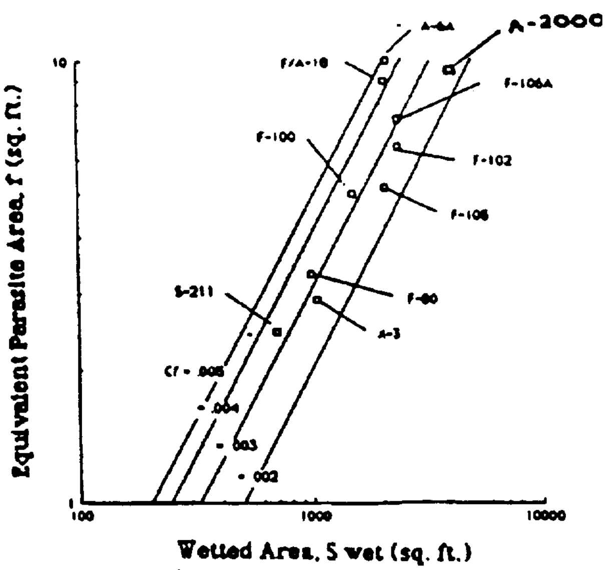


Figure 9.2.2 - Equivalent Parasite Areas

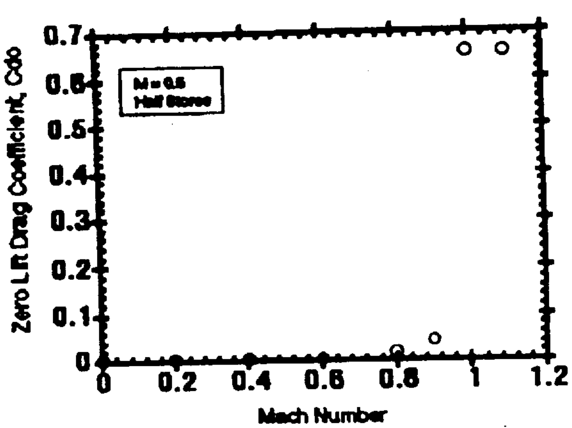


Figure 9.2.3 - Aircraft Drag Divergence

10.0 Stability and Control

The stability and control analysis for the A-2000 is divided up into three sections: These include Methodology, Stability Derivatives, and Handling Qualities.

10.1 Methodology

The most accurate methods were used wherever possible to evaluate the aerodynamic, thrust, and control derivatives of the A-2000. References 15 and 16 present rapid methods for this and were used interchangeably.

With the exception of the V-tail, the A-2000 is fairly conventional in configuration, and the analysis was straightforward. The aircraft is stable throughout its performance envelope, with a static margin between 5% and 10%. On the other hand, the A-2000 V-tail required some unique considerations due to the fact that it is a full-flying differential stabilizer. Rather than employing elevators and rudders, the entire tail moves as a control surface. Each tail is mounted to the engine housing at a 30 degree dihedral angle. Actuators in the fuselage are capable of rotating the tails independently about their own axis to provide the desired control deflection. Control coupling is inherent to this layout, and this increased the difficulties of evaluating the stability and control derivatives.

Figure 10.1.1 demonstrates how this control coupling arises due to a differential deflection. The normal force (lift curve slope) coefficient, C_{LiT}, is shown perpendicular to each tail. Normal force increases on the left-hand tail, while normal force decreases on the right. This normal force couple produces a rolling moment with a lever arm of 2YT. At the same time, this deflection produces a net side force coefficient of $2C_{YiT}$ in the positive Y direction. The side force acts at a lever arm, L_V, to produce a destabilizing (negative) yawing moment. The yaw moment will cause the nose of the aircraft to yaw away from the roll maneuver, rather than into it. This will cause the well known dutch roll mode to be a prominent effect on handling qualities. If needed, cross-coupling difficulties such as these can be handled with the aid of a stability augmentation system.

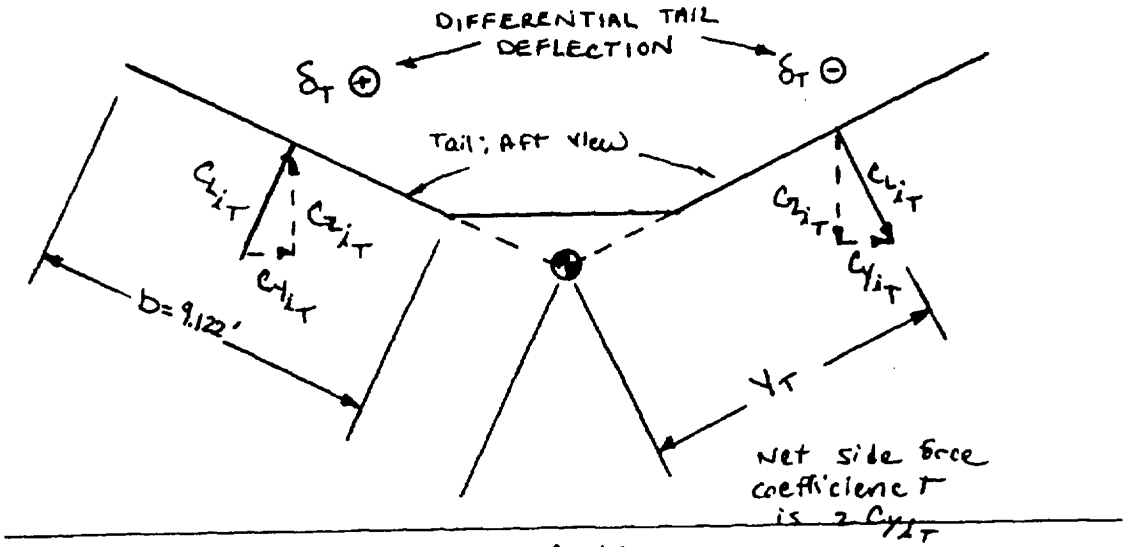


FIGURE 10.1.1: CONTROL COUPLING

Figure 10.1 - V-Tail Control Coupling

Unlike a wing, which is composed of two halves and does not move, the differential V-tail surfaces can move independently. Thus, aerodynamic characteristics were defined on the basis of exposed surface area for each tail. Aspect ratio, taper ratio, and quarter-chord sweep were all defined in terms of one tail, having a planform area 75 ft^2. as shown in figure 6.3.1. The lift curve (normal force) slope was then calculated based upon the actual planform parameters. The lift due to the engines in between the tails was accounted for as fuselage lift. The normal force has both horizontal and vertical components, involving sine and cosine functions of the dihedral angle. This was accounted for by taking either the projected force or the projected area of the tail. Actual planform area multiplied by Sin (Γ) yields the projected vertical area. When calculating derivatives for the vertical and horizontal tail individually, the projected areas were used to isolate the effects of the vertical or horizontal components of this normal force. This isolation could also be accomplished by calculating the horizontal or vertical component of the normal force, while using the actual tail area. However, care must be taken not to use both projected area and projected force in the same calculation, because this would yield erroneous results.

10.2 Stability and Control Derivatives

The stability and control derivatives of the A-2000 were evaluated for three critical flight conditions, as shown in Table 10.2.1. Flight condition I (hereby referred to as F.C. I) is the landing approach configuration. This is critical due to the landing flare requirement, and the possibility of an aborted landing with a steady-state pull-up maneuver. F.C. II is the second combat pass, with high g' loadings associated with the climb and pull-out phase. Finally, it was felt that handling qualities should be evaluated at the high-speed dash condition. Detrimental handling qualities, such as an underdamped phugoid mode, could cause weariness in the pilot as well as increase his workload if he tries to compensate with control deflections.

Flight Condition	**F.C. I Landing / Approach**	**F.C. II Combat / 2nd Pass**	**F.C. III Cruise (Dash-to)**
Mach	0.2	0.6	0.76
Altitude	Sea-Level	Sea-Level	Sea-Level
Weight	28,378	37,395	45,779
Fuel Remaining	4%	55%	97%
Load Factor	1.0	6.0	1.0
Configuration	gear down	1/2 bomb load	full bomb load
Lift Coefficient	0.8	0.7	0.09

Table 10.2.1 - Flight Condition Definitions for Stability and Control Analysis

Longitudinal Derivatives	F.C. I	F.C. II	F.C. III
$C_{L\alpha}$ (1/rad)	4.108	4.611	4.891
$C_{M\alpha}$ (1/rad)	-0.215	-0.242	-0.254
$C_{L\alpha}$ (sec/rad)	1.648	2.717	3.733
$C_{M\alpha}$ (sec/rad)	-0.727	-0.862	-0.763
$C_{D\alpha}$ (sec/rad)	0	0	0
C_{Lu} (sec/ft)	0.0479	0.0697	0.0988
C_{Mu} (sec/ft)	-0.357	-0.0396	-0.026
C_{Dq} (sec/ft)	0	0	0
C_{Lq} (sec/rad)	2.468	2.832	2.972
C_{Mq} (sec/rad)	-1.435	-1.704	-1.65
C_{Txu}	0.202	0.0306	0.0296
Directional Derivatives			
C_{MTu}	0.0163	0.0025	0.0024
$C_{y\beta}$ (1/rad)	-1.432	-1.432	-1.432
$C_{l\beta}$ (1/rad)	-0.905	-0.902	-0.901
$C_{n\beta}$ (1/rad)	0.0695	0.0711	0.0723
$C_{y\beta}$ (sec/rad)	-0.0132	0.00084	0.0197
$C_{l\beta}$ (sec/rad)	0.000318	0.000691	0.000798
$C_{n\beta}$ (sec/rad)	0.00487	0.000311	0.00726
$C_{nT\beta}$	0.00452	0.0023	0.0015
C_{yr} (sec/rad)	0.138	0.138	0.137
C_{lr} (sec/rad)	0.364	0.418	0.424
C_{nr} (sec/rad)	-0.0924	-0.0513	-0.0505
C_{yp} (sec/rad)	0.00838	-0.0037	-0.0156
C_{lp} (sec/rad)	-0.309	-0.289	-0.298
C_{np} (sec/rad)	0.102	0.00084	-0.00009
Control Derivatives			
C_{Lih} (1/rad)	0.349	0.343	0.351
C_{Mih} (1/rad)	-0.429	-0.423	-0.432
C_{Dih} (1/rad)	0	0	0
$C_{l\delta a}$ (1/rad)	0.2	0.192	0.172
$C_{y\delta h}$ (1/rad)	0.123	0.126	0.128
$C_{l\delta h}$ (1/rad)	0.0178	0.0182	0.0184
$C_{n\delta h}$ (1/rad)	-0.0439	-0.045	-0.0454

Table 10.2.2 - Stability Derivatives

10.3 Handling Qualities

The methods of reference 17 were used to evaluate the handling qualities of the A-2000 for the three flight conditions. The results of the dynamic stability characteristics are tabulated in Table 10.3.1 and compared to the military requirements for handling qualities. The table shows that the A-2000 meets level 1 requirements for nearly all flight conditions. Level II requirements are met for all flight conditions in the dutch roll mode, as well as the roll time constant for F.C. I. The lightly damped dutch roll mode is a consequence of the wing sweep, large tail dihedral angle, and cross-coupling effects as previously discussed. The combination of the two yields a relatively large dihedral effect when compared to data for the F-4. $C_{l\beta}$ is a factor of 6 higher than the dihedral effect of the F-4 (reference 15). The low dutch roll damping is a trade-off between maneuverability and tame handling qualities.

Table 10.3.1 - Evaluation of Handling Qualities

Regulated Parameter	Requirements Level I / II / III	A-2000 Flight Condition F.C. I / F.C. II / F.C. III
ω_{nsp} (rad/sec)	0.79-3.9/ - / - (min - max)	0.8 / 2.5 / 3.1
ζ_{sp}	0.35-1.3 / .25-2.0 / 0.15- (min - max)	0.57 / 0.49 / 0.38
ζ_p	.04 / 0 / - (min)	0.071 / 0.26 / 1.2
ω_{nd} (rad/sec)	1.0 / 0.4 / 0.4 (min)	0.87 / 2.57 / 3.36
ζ_d	0.19 / 0.02 / 0.02 (min)	0.21 / 0.079 / 0.13
$\zeta_d\omega_{nd}$ (rad/sec)	0.35 / 0.05 / - (min)	0.18 / 0.2 / 0.44
Roll time constant, T_r (sec)	1.0 / 1.4 / 10 (max)	1.08 / 0.37 / 0.29

Spiral: time to double amplitude, T_S (sec)	12 / 12 / 4 (min)	13.2 / 15.4 / 13.3

Subscripts:

- sp Short Period Mode
- p Phugoid Mode
- s Spiral Mode
- d Dutch Roll Mode
- r Roll Mode

Symbols:

- z Damping Ratio
- w_n Natural Frequency

11.0 Avionics

The A-2000 employs only the necessary avionics. The basic requirements are dictated by the design requirements.

- Capacity to deliver ordnance in close proximity to friendly troops Day, Night, and Adverse Weather conditions
- The primary mission will be conducted at treetop level
- Reduce the pilots workload for pilot to maximize mission effectiveness

Current trends indicate that integrated avionics are vital to future combat situations.

The A-2000 considered the following principals in choosing its avionics.

- Provide adequate avionics to perform mission
- Minimize maintenance

The A-2000 does not incorporate a large active radar system. This is to reduce cost and weight. Also, the A-2000, being an attack plane, is not able to realize the potential of such a radar system. Radars built in fighter aircraft are designed with air to air dogfights in mind, and an attack airplane is not properly suited for the aerial dogfighting role. Also, not having active radar allows some degree of protection from radar seeking missiles. The A-2000 utilizes detection, avoidance, and counter-measure systems for protection. The following is incorporated:

- Radar warning receiver (RWR) such as the ALR-69 is installed to help detect incoming radar signals. It is low powered and does not produce a strong signal.
- The RWR is coupled with Plan Position Indicators(PPI) to help locate the approximate range of threat radars.
- Flare and chaff is installed in the aft section of the plane to deceive incoming missiles.
- Also, an Electronic Counter Measure (ECM) is employed in the nose section to assist in penetrating hostile airspace.

Other basic avionic equipment include Inertial Navigation System (INS), TACAN, and communication equipment such as VHF/UHF/IFF. All of these are either externally mounted to the outer skin, or placed internally behind the cockpit as shown in Figure 11.1.1.

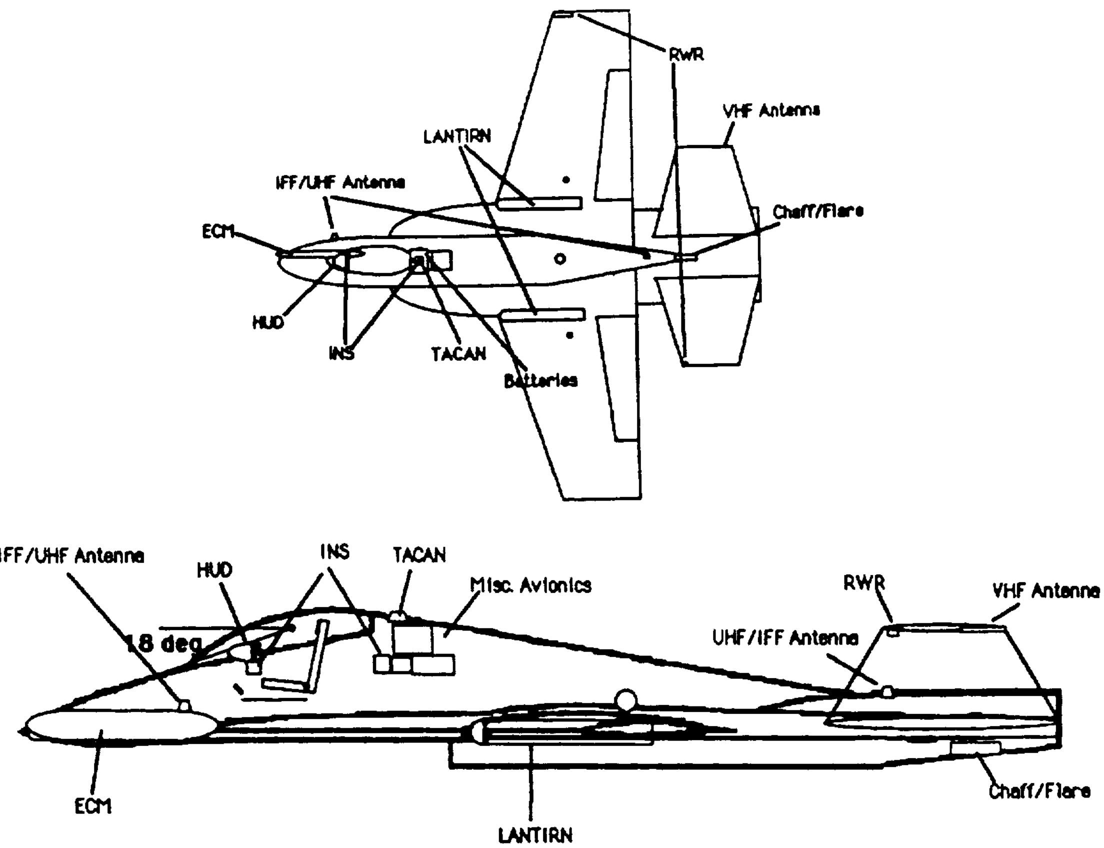


Figure 11.1.1 - Avionics System Layout

The bulk of the avionic duties is performed by the Low Altitude Navigation and Targeting Infrared System for Night (LANTIRN)[18]. In the A-2000, the entire LANTIRN system, including targeting and navigation pods, is employed. The system is capable of low level terrain following, accurate weapons delivery , and operations in all weather .

The LANTIRN pod is shown in Figure 11.1.2. The navigation pod includes a terrain following radar, wide field-of-view infrared sensor, digital computer, power supply and environmental control unit. The targeting pod includes a narrow field-of-view infrared sensor, laser transmitter/receiver, automatic image tracker, missile boresight correlator, digital computer, power supply and environmental control unit. The pods are coupled with a heads-up-display (HUD) which are linked to all sensors.

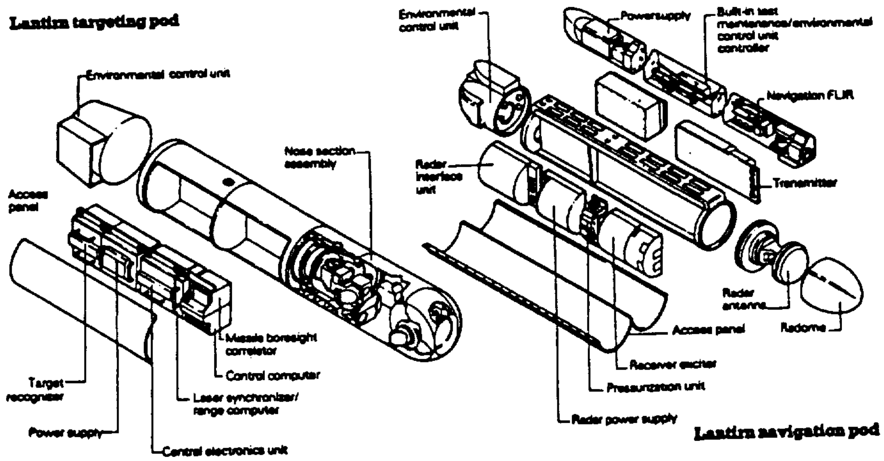


Figure 11.1.2 - LANTIRN Targeting and Navigation Pod (taken from 3)

The Lantirn system is internally mounted in the wing root, close to the inlet wells. The podded external installation has been incorporated into a modular form for the internal mounting. Dual harnesses, both smaller and lighter than pods will house the targeting and navigation systems. The modular installation will provide ease of maintenance. Access panels are provided on top of the wing and titanium armor plating is installed below.

At present, the government will spend $3 billion on 692 LANTIRN systems for its current inventory of airplanes[22]. This equates to approximately $4.5 million per system.

12.0 Systems Layout

The following considerations went into the system layout of the A-2000:

- Survivability: the critical criteria
- Simplicity
- Cost
- Performance
- Maintainability

12.1 Cockpit

The following drivers were important to the cockpit layout:

- Good visibility
- Comfort and accessibility to controls and instruments
- Providing vital information in an organized manner
- Protection

As with the A-10, the A-2000 seats the pilot high in the perch to afford maximum visibility without compromising protection. The pilot has 18 degrees of visibility over the nose. side-view affords the pilot nearly 50 degrees of visibility, and the canopy offers a 270 degree field of vision with the only blind spot being directly behind the pilot.

The pilot seat is surrounded with titanium armor for protection. Bullet-proof Plexiglass is used for the canopy. The cockpit is equipped with a standard ejection seat. The cockpit layout is similar to the F-16. The HOTAS (Hands On Throttle And Stick) is utilized with a side mounted stick, instead of being center console mounted, for comfort. Everything is readily accessible from one position.

The instrumentation is kept simple as shown in Figure 12.1.1. Important readings are channeled to the HUD. Other necessary information is shown on the head-down-display (HDD) and two multi-function CRT's.

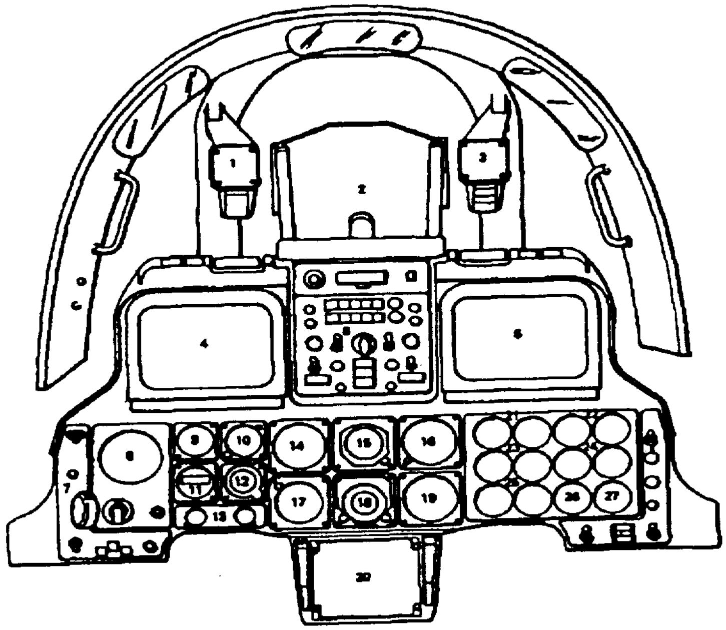


Figure 12.1.1 - Cockpit Instrumentation (taken from 3)

12.2 Flight Control System

The A-2000 utilizes a fly-by-wire system. The system is installed to save weight and to assist control, since the A-2000 incorporates a full flying V-tail. There is no need for a stability augmentation system since the A-2000 is stable in all flight conditions. All control systems are redundant to guard against system failure and for protection. As shown in Figure 12.2.1, components such as computers, actuators, and wiring, are placed far apart from each other for survivability.

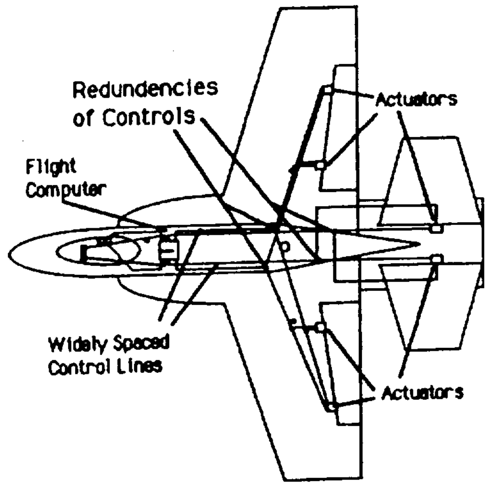


Figure 12.2.1 - Flight Control System

12.3 Fuel Provisions

One of the most vulnerable portions of the aircraft is the fuel system. In previous wars, designers found that fuel tanks required a high degree of protection including self-sealing and tear-resistant tanks[3]. In the A-2000, the fuel system layout was designed with this in mind.

The following features were incorporated into the fuel system layout:

- There is one central, compartmentalized and armored fuel tank
- The tank is internal and centerline mounted to expose minimal area
- The tank is self-sealing and tear-resistant to protect against spillage
- Special foam is filled in and around the tank to slow spillage in case of puncture.
- Fuel lines and valves are run through the tanks much as possible for protection
- Pipes are self-sealing
- Check valves prevent fuel flow into damaged tanks
- There is only one tank. It is separated into small compartments

The fuel tank is capable of carrying over 7700 lb of JP-4 fuel internally (see A-2000 fuel weights). A center of gravity control pump, shown in Figure 12.3.1, is present to limit the C.G. travel due to fuel burn. A fuel vent is located on top of the fuel tank to vent the tanks. The fuel intake system is located on the port side.

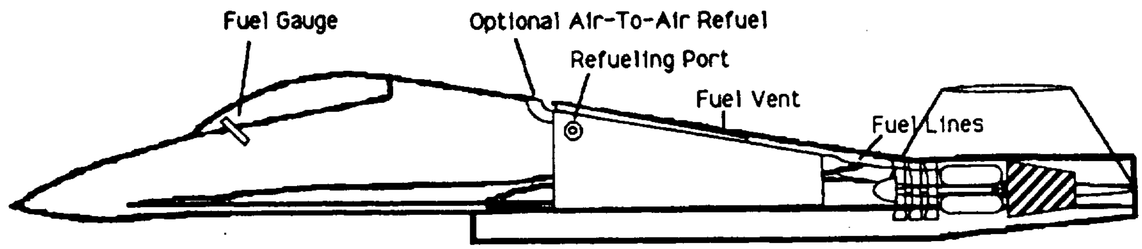


Figure 12.3.1 - Fuel System Layout

For the ferry mission, two external 300 gallon tanks are needed. These are mounted on the wings in place of bombs. Additionally, an optional air-to-air refueling port can be installed on top of the fuselage.

12.4 Armor

In previous wars, many planes have fallen prey to small arms fire. To counter this, some aircraft such as the A-10's utilize heavy armor plating. The armor comprises a quarter of the plane's empty weight[3]. The A-2000's armor incorporates similar concepts:

- Maximum allowable (by weight) protection to pilot and vital equipment
- Protection from small arms fire, especially 23mm API and .50cal rounds

The A-2000 incorporates titanium-alloy armor. The pilot is surrounded by titanium tub made of alloy plates bolted together. The plates thickness varies with the thickest portions being the deck and the front.

The titanium alloy has a ballistic nylon molding to help reduce the fragmentation damage from the 23mm API round which breaks up on impact. The armor has an aluminum honeycomb backing to help absorb shock (blast). The entire armor is designed with data that predicts armor requirements for moving targets to reduce weight [19].

Other critical areas requiring armor are the ammunition drum, engines, and avionics. The drum has trigger plates combined with the titanium to help defeat the incoming rounds. The engines also utilize titanium plates for protection. Armor is included between the engines for protection against engine fragmentation in case of failure or damage.

The total armor weight is 2000 lbs with 800 lbs placed in the proximity of the pilot. The remaining 1200 lbs is distributed along the airplane: the engine compartments with 600 lbs and surrounding areas, avionics . LANTIRN with 200 lbs, the fuel system with 200 lbs, and the ammunition drum with 200 lbs.

12.5 Electrical

As with the other systems, the design philosophy of the electrical system is directed toward survivability. The electrical system includes the lighting, avionics, actuators, computers, and instruments. The electrical system was designed with the following considerations:

- System redundancy for survivability
- Battery backup in case of power failure
- Separation of electrical lines so that one hit won't take out the entire system.

The system is powered by generators and has a battery backup in case of APU failure.

12.6 Hydraulic

The A-2000's hydraulic system runs the landing gear system including brakes, gear retraction, and bay doors. Hydraulic power is provided by engine compressor bleed.

12.7 APU

The A-2000 utilizes an auxiliary power unit (APU). The unit powers nearly everything during ground operations before the engines are started. The APU allows for minimum ground support so that external power sources aren't needed to start the engines. The APU is be located in between the engines.

12.8 Miscellaneous Systems

12.8.1 Oxygen

The oxygen system provides the pilot with oxygen during flight. The system is stored in a box under the seat . It is an On Board Oxygen Generating System (OBOGS). This reduces the need for an on-board replenishment system.

12.8.2 Fire Suppression

Many attack airplanes are lost through fire[19]. To counter this, A-2000 has a self-actuating fire suppression system. The system protects the pilot, avionics, engines, and fuel system.

13.0 Ground Support Requirements

The RFP calls for an airplane capable of near continuous ground operations. To meet this criteria, the A-2000 was designed for ease of maintainability and minimum ground time. Ground support hardware and manpower requirements should be minimized for support at forward operating stations. Typical ground support requirements include weapons loading, refueling and engine restarting.

The A-2000 eliminates the need for external starting equipment by incorporating an APU and hydraulic starter. Hydraulic pressure is stored during engine operation and can be bled off to start the APU. During cold weather operation, the APU acts as a heater to prime the engine.

Weapons loading is simplified by the low wing position. External racks are within reach of ground crews. Access panels beneath the fuselage are provided for reloading ammunition. Refueling is accomplished through a port near the top of the fuselage within reach of a crew member standing on the wing. Although the port is located high, it takes advantage of gravity feed which will reduce the need for a high pressure pumping system.

14.0 Armament

Ordnance that is carried by the A-2000 is dictated by the RFP. These requirements are:

- 20 Mk-82 bombs at 505 lbs each
- 2 AIM-9L Sidewinders
- 1 GAU-8 30-mm cannon system with 1840 rounds

The twenty Mk 82 bombs are distributed with six on each wing in three bomb clusters. Eight are mounted conformally on the fuselage in between the inlets. The conformal mounts handle four bombs a piece. The A-2000 carries two wing-tip mounted AIM-9L sidewinders for protection against other aircraft. (Figure 14.1.1) The GAU-8 has been replaced by the GAU-12.

The GAU-8 was replaced for these reasons:

- Approximately 2000 lb (loaded) weight savings
- Internal space savings: decrease in length of 100 cm
- Power requirement to drive the weapons system: from 54HP to 13.94HP
- Recoil force: decrease of 2000 lbs ave. and 9000 lbs peak

The GAU-12 has practically the same performance as the GAU-8 for a large savings in weight and size. The GAU-12 offers comparable projectile penetration power as the GAU-8. (Table 14.1.1). The penetration power was a parameter devised to attempt to model the effectiveness of a projectile. It was defined as the kinetic energy of the projectile divided by the frontal area of the projectile.

	GAU-8/A	**GAU-12/U**
Firing Rate (shots/minute)	2100/4200 (min/max)	3600/4200 (avg/max)
Muzzle Velocity (ft/sec)	3500	3600
Dispersion (milliradians)	5	6
Projectile Kinetic Energy (ft-lb$_f$)	184660	112988
Projectile Penetration Power (ft-lb$_f$/ft^2)	6.07×10^6	5.35×10^6

Table 14.1.1 - Cannon Firepower Comparison

Other comparable weapons were researched. One such weapon was the GPU-5/A (GAU-13). It was rejected due to it small ammunition capacity. Other weapons currently available do not offer comparable armor piercing capability. Appendix A7 contains a comparison of the GAU-8/A and GAU-12 specification.

As with most close air support aircraft, the A-2000 carries a wide variety of ordnance. The AGM-65 Maverick missile may be used in place of the Mk-82 depending on the mission. Multiple hardpoints are located along the wing span for additional weapons storage.(Figure 14.1.1)

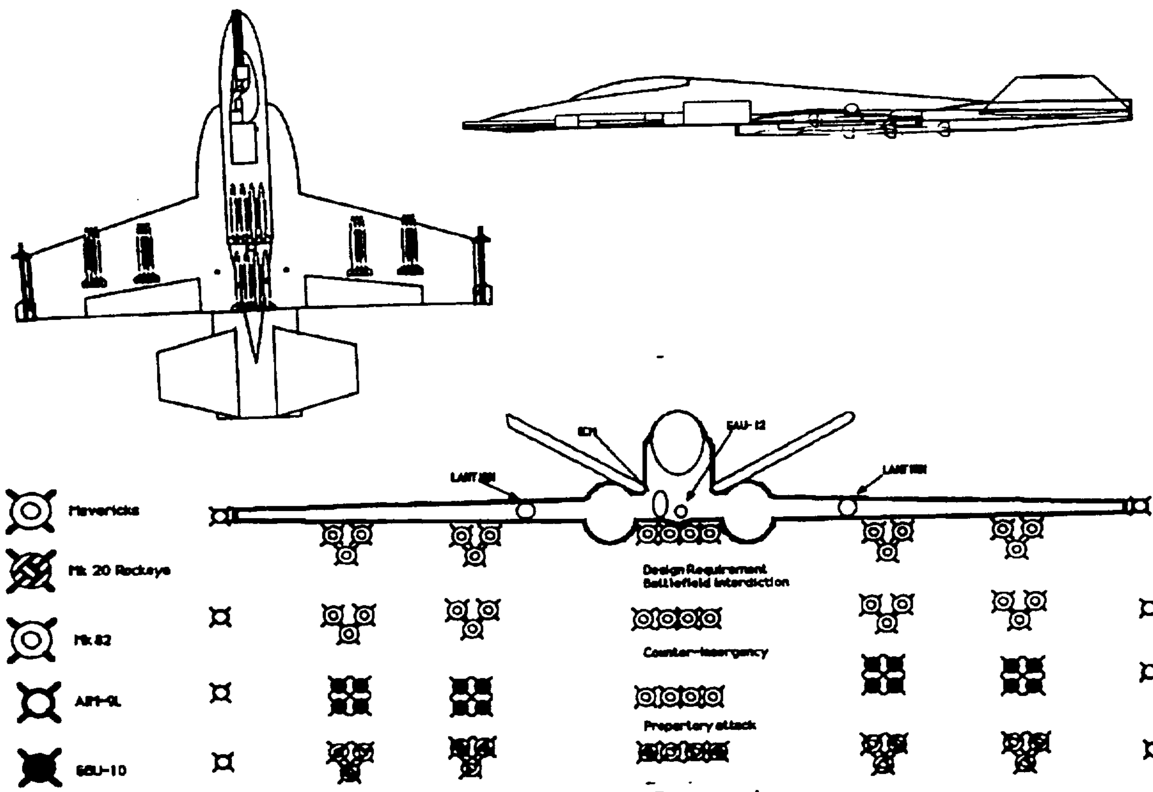


Figure 14.1.1 Weapon Integration

15.0 Cost Analysis

The empirical aircraft cost estimation methods of Reference 20 were used to calculate the unit cost of the A-2000 in 1991 dollars. This is the price that the customer pays per airplane. The unit cost was calculated from two phases of the airplane program: Research, Development, Test and Evaluation (RDTE) and Manufacturing. The RDTE phase is the time in which preliminary conceptual design takes place up to the point where the design is finalized for flight test certification and production. The manufacturing phase is the period in which the actual production of the aircraft occurs[20]. Table 15.1.1 shows the breakdown of the RDTE and manufacturing costs of the A-2000 based on the production of 500 aircraft over six years, resulting in a unit cost of $17.6 million.

Research, Development, Test and Evaluation			
	Airframe Engineering and Design		139.9
	Development Support and Test		53.7
	Flight Test Aircraft (401.2)		
		Engine and Avionics	22.2
		Manufacturing Labor	164.2
		Manufacturing Material	20.3
		Quality Control	21.3
		Tooling	173.2
	Flight Test Operations		10.9
	Profit (10% of total cost)		75.7
	Finance Rate (10% if total cost)		75.7
Total Research, Development, Test and Evaluation			757.2
Manufacturing Cost			
	Aircraft Engineering and Design		175.1
	Production		
		Engine and Avionics	3692.8
		Manufacturing Labor	1513.0
		Manufacturing Material	661.2
		Tooling	293.3
		Quality Control	196.7
	Flight Test Operations		80.0
	Finance Rate		734.7
	Profit		734.7
Total Manufacturing			8081.5
Total Acquisition Cost			8804.9
Unit Cost (500 Aircraft)			17.7

All costs in millions of dollars.

Table 15.1.1 - RDT&E and Manufacturing Cost Breakdown

The Life Cycle Cost is the cost from the initial design concept to the disposal of the aircraft. It includes the operational and disposal costs of the aircraft along with the RDTE and manufacturing costs. Table 15.1.2 shows a comparison of Life Cycle Cost and Unit Cost of the airplane for the years 1991 and 2000. The table shows that the airplane will increase approximately $1 million in nine years due to inflation, but the technology used presently in 1991 will decrease in cost by the year 2000, likewise, the cost will decrease.

One of the major costs of the A-2000 is the labor cost to manufacture the aircraft to production standards. The number of hours needed to build the A-2000 is based on an empty weight of 17,000 lbs, a velocity of 550 knots, and the total number of airplanes built in a program, 500. The three factors, along with a pay rate of $62.00 an hour projected to year 1991[20] (includes direct engineering labor, overhead, general and administrative costs), make the total engineering labor costs extremely high.

Another major cost of the A-2000 is the engine and avionics. The engine price, based on a maximum sea-level thrust of 13,500 lbf, is roughly $1 million for each engine[21]. The aircraft is equipped with the LANTIRN system, which has a purchase price of $4.5 million, which is about 25% of the total unit cost of the airplane[22]. The total cost of the avionics equipment per airplane is $5.5 million. Yet even with the high costs of the avionics systems, the A-2000 is still comparatively priced with its counterparts (F/A-18, $35 million[23], F14-D, $60.6 million[24]).

	Year 1991	**Year 2000**
RDTE Costs	757.2	807.2
Operational Costs	13091.3	13291.9
Manufacturing Costs	221.5	227.2
Disposal Costs	221.5	227.2
Unit Price Per Airplane	17.7	18.4
Life Cycle Cost	22151.4	22722.0

Table 15.1.2 - Comparative costs for years 1991 and 2000

16.0 Manufacturing

16.1 Manufacturing Facility

The A-2000 is of fairly conventional design, utilizing lithium aluminum as the primary structural material and a small percentage of composites. This permits fairly conventional manufacturing processes which should allow, with few modifications, the use of existing assembly facilities. The following outline describes the basic layout and order of assembly, based upon the F/A-18 assembly process. The contribution of F/A-18 Project Engineer Bechara Charbel is greatly appreciated. His comments and suggestions, during a tour of the assembly plant, were influential to this section[25].

16.2 Overall Assembly Procedure

Plant area will depend on equipment sizes and quantities. The fuselage is first assembled and the landing gear installed immediately afterward to allow for ease of maneuvering. The fuselage/landing gear assembly is then rolled to the next station where the avionics and systems are installed. Once completed, the control surfaces are installed and the vertical tail sections are assembled. The sections are mated to the fuselage and the propulsion system is installed. Simultaneously on the other side of the plant the wing halves are produced and assembled. The complete assembly is wheeled to the next work station where the gun and ammo box are installed. Finally, all systems are checked and a quality control inspection is performed.

16.3 Fuselage-Aft Portion

Once the parts are manufactured, the aircraft assembly begins with the fuselage. The plane is assembled outward from the middle, beginning with the main wing support bulkheads. A steel rig is used to maintain precise tolerances on the structure, since it will be used as a reference on which all subassemblies are mounted. Subsequent bulkheads and longerons are assembled to complete the aft portion of the fuselage up to the aft pressure bulkhead.

16.4 Control Surfaces

Once assembled, the V-tails are attached to the fuselage in the engine cowl area. The dorsal air-brake is then mounted to the top of the fuselage. Control actuators are tested to ensure adequate clearance for the control surface deflection.

16.5 Systems

Mechanical and electrical systems are continuously installed during the fuselage buildup process. Electrical, fuel, and hydraulic systems are built onto the support structure, and operational checks are conducted to ensure safety and reliability.

16.6 Wings

Fuel bays, electric wire harnesses, hydraulic lines, and actuators have been installed during the assembly of the wing. Once the wingbox is completely assembled, it is then attached to the support bulkhead on the fuselage. Stands are used to support the wingtips during attachment to the fuselage.

16.7 Landing Gear

Once the fuselage is built and rigid enough to support its own weight, the main landing gear is installed. This provides ease in maneuvering the aircraft to the next station.

16.8 Fuselage-Forward Portion

The forward portion of the fuselage, consisting of a pressure bulkhead, cockpit, canopy, and nose gear is next attached to the aft fuselage. Once attached, the nose gear and gatling gun are installed.

16.9 Propulsion System

The A-2000 is designed to allow ease of propulsion system maintenance. With the inlet ducts and engine cowl built into the fuselage, access doors similar to those of the F-18 allow quick installation and removal of the turbofan engines. The engines can be loaded via a hydraulic cart in the assembly plant or on the airfield.

Conclusion and Recommendations

The A-2000 is shown in this report to be a highly competitive and effective CAS aircraft. Designed with maneuverability and serviceability in mind, and having met all the RFP requirements, the A-2000 should prove invaluable to ground troops for decades to come. Some major considerations on the A-2000 are as follows.

Performance

- MIL-A-8785C Level I handling requirements have been met for nearly all natural frequency responses.
- Acceleration from M = 0.3 to M = 0.5 in 7.7 seconds far exceeds the RFP time limits of 20 seconds.
- Load factor requirements of 4.5 sustained and 6.0 instantaneous are easily surpassed with values of 6.0 and 7.5, respectively.
- High thrust-to-weight ratios and low wing loadings combine to achieve a re-attack time of 23 seconds.
- The take off ground roll limit of 2000 ft is attainable up to an altitude of 6000 ft above sea level. The sea level take off ground roll is a mere 1480 feet with a take off velocity of 158 kts. From a grass runway, the A-2000 takes off in 1820 feet.
- The landing ground roll limit of 2000 feet is easily met up to an altitude of 4000 feet above sea level. The minimum sea level ground roll distance is 1150 feet with a landing speed of 83 kts.

Armament

- The GAU-12 provides 90% of the penetration power of the GAU-8 while weighing 44% less fully loaded.
- The average firing rate of the GAU-12 is over 70% higher than that of the GAU-8.
- The substantial weight saving coupled with increased firing rate and modest loss of penetration power provides for a more versatile weapon.
- The GAU-12 will be effective against a variety of ground targets including artillery, personnel carriers, and light tanks.

Cost

- The use of a previously existing engine and minimal avionics systems helps to keep the unit cost at a reasonable level.
- The moderate technical make up of the A-2000 will combine with ease of access to critical components to produce minimal operation and maintenance costs.

Alternate Missions

- A variety of hard points along the wing planform provide for the capability of carrying numerous different weapons.

Recommendations For Further Analysis

- The A-2000 fails to meet MIL-A-8785C Level I handling requirements for the Dutch Roll natural frequency. A reduction in the dihedral angle and possible re-sizing of the tail selection should be investigated for a solution to this problem.
- Wind tunnel tests should be performed to determine optimum vortex generation by the strake and consequent non-linear generation.

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